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UC Davis ECLIPSE ROCKETRY:

Mission Design for a Two-Person Mars Flyby in 2018

Team Members

Alvarez, Roberto*	Reentry
Cervantes, Eduardo	Nutrition
Cheol-Kim, Hyun	Illustration
Enriquez, Daniel*	Life Support, Editing
Fitzpatrick, Kevin*	Radiation Shielding
Holmquist, Ben**	Spacecraft design
Hurd, Christian	Communications
Jauregui, Daniel	Launch Systems
Leng, Jack	Animation
Montes, Carlos**	Mission Design Lead
Ng, Stephan	Radiation Shielding
Ovalle, Paulina	Spacecraft Design
Pang, Janice	Formatting
Pensado, Alejandro*	Cost, Trajectory
Revolinsky, Patricia*	Mental Health
Tamboh, Terence*	Trajectory
Townsend, Molly**	Human Element Lead
Welby, Bradley*	Power Systems
Wong, Christopher	Launch Systems
Yazdi, Anahita*	Communications
***Subsection Lead**	****Section Lead**
Dr. Nesrin Sarigul-Klijn	Faculty Adviser

Acknowlegments

Dr. Marti Sarigul-Klijn	Faculty Reviewer
Dr. Stephen K. Robinson	Faculty Reviewer
Dr. Henderson	Faculty Reviewer
Charmaine Seguro	Contributor
Donald Wong	Contributor
Steven Wong	Contributor
Robert C. Singletary	NASA Langley

UC Davis Mechanical & Aerospace Faculty

Contact Info

Ben Holmquist (Team Lead)
bwholmquist@ucdavis.edu
(925) 519-4859

Dr. Nesrin Sarigul-Klijn
nsarigulklijn@ucdavis.edu
(925) 519-4859

Team Listserve
rockets@ucdavis.edu

List of Acronyms

ANITA	Analyzing Interferometer for Ambient Air
ARED	Advanced Resistive Exercise Device
ARS	Atmospheric Revitalization System
BEIR	Biological Exposure to Ionizing Radiation
BMD	Bone Mineral Density
CBM	Common Berthing Mechanism
CCDev	Commercial Crew Development
CLSS	Close-Loop Life Support System
CME	Coronal Mass Ejections
COL-BERT	Combined Operational Load Bearing External Resistance Treadmill
DSN	Deep Space Network
ESWL	Extracorporeal Shockwave Lithotripsy
FESC	Food, Equipment, Supplies, and Cargo
FH	Falcon Heavy
FRT	Free Return Trajectory
GCR	Galactic Cosmic Radiation
HDPE	High Density Polyethylene
HLLV	Heavy Lift Launch Vehicle
HRF	Human Research Facility
HZE	High Atomic Number High-Energy Particles
IMLEO	Initial Mass in Low Earth Orbit
ISIS	International Subsurface Interface Standard
ISP	Specific Impulse
ISS	International Space Station

LCRD	Laser Communications Relay Demonstration
LED	Light-Emitting Diode
LEO	Low Earth Orbit
LH2	Liquid Hydrogen
LOX	Liquid Oxygen
LV	Launch Vehicle
MPLM	Multi-Purpose Logistics Module
MRI	Magnetic Resonance Imaging
MRO	Mars Reconnaissance Orbiter
NASA	National Aeronautics and Space Administration
PICA	Phenolic Impregnated Carbon Ablator
PSDC	Paragon Space Development Corporation
RAD	Radiation Assessment Detector
REID	Radiation Exposure Induced Death
RF	Radio Frequency
RTG	Radioisotope Thermoelectric Generator
SLS	Space Launch System
SNC	Sierra Nevada Corporation
SOI	Sphere of Influence
SPE	Solar Particle Event
TMI	Trans-Mars Injection
TRL	Technological Readiness Level
TOF	Time of Flight
VPCAR	Vapor Phase Catalytic Ammonia Removal

Executive Statement

ECLIPSE Rocketry is a student team from the University of California at Davis (UCD). As part of the renowned SpaceEd program at UCD, ECLIPSE is influenced by some truly wonderful faculty members and is proud to be part of a history of innovation in spaceflight. We are diverse in every way, with individuals from many disciplines, including biomechanics, information design, aerospace, and particle physics backgrounds. What unites us, beyond a common interest in rocketry and spaceflight, is our passion for new bold ideas that have the power to change the world.

ECLIPSE continues the SpaceEd tradition of innovative research at UC Davis. Since 2001, SpaceEd has provided a home for students of all experience levels to investigate space-relevant topics such as flight dynamics, propellant sloshing, and reusable space transport. ECLIPSE has drawn on a valuable pool of research and connections supplied by this program to build the report that follows.

The Mars Society Design Competition, hosted jointly with Inspiration Mars, presents a unique challenge and exciting opportunity. In designing a Mars flyby mission to occur in 2018, ECLIPSE has identified some important criterion upon which the following proposal is based, taken from our own analysis and the rules provided by the Mars Society:

- Design a two-person Mars flyby mission for 2018 as cheaply, safely, and simply as possible
- Treat cost and technical design quality as top priorities, followed by simplicity and schedule
- Address all aspects of the mission design, including vehicle selection, trajectory, crew health, life support, attitude control, radiation protection, communications, reentry, and landing
- Provide a realistic schedule, from mission development through flyby through final reentry
- Provide a cost breakdown of all mission components, which arrives at a total mission cost
- Include on-board research capabilities to maximize mission value and appeal to investors

ECLIPSE is a twenty person team structured in various topical subsections, allowing each individual to specialize in one particular area. This exposed our members to a wide array of previously unfamiliar knowledge, gave leadership experience, and increased technical writing confidence. The content in this report is diverse and addresses the major challenges of deep space exploration, including designs for an efficient orbital assembly, low-cost launch options, novel radiation shielding concepts, and a comprehensive crew health section. We have documented our response to the above requirements in order to contribute to the Martian effort being spearheaded by Inspiration Mars.

ECLIPSE has developed a mission plan that relies on available and proven technologies, which accomplishes several things. First, these technologies minimize research costs and their manufacturing techniques are well developed. Second, they have proven reliability records, thus decreasing mission risk. Third, these technologies can be quickly integrated into a concrete mission timeline, meaning a 2018 launch window is indeed feasible.

Mission cost and technical quality of design exist in delicate balance in all space missions. We believe the proposal below is affordable while still operating at a high technical level. Due to the time-sensitive nature of Free Return Trajectory (FRT) launch windows, ECLIPSE strove to design a mission schedule that was realistic and simple to implement.

ECLIPSE recommends a multi-week assembly occurring in low earth orbit, leading up to a Trans-Mars Injection burn on 05 JAN 2018. This launch date corresponds with a 501 day FRT, this trajectory minimizes system load. The low-energy requirements of the transfers involved reduce launch complexity and cost.

The craft and crew fly within 200 miles of the Martian surface 228 days later, marking the first time human eyes have viewed the red planet. 273 days later, the Dragon will reenter Earth's atmosphere after jettisoning all excess equipment, returning the crew safely home. Through the use of primarily private vehicles and commercially developed equipment,

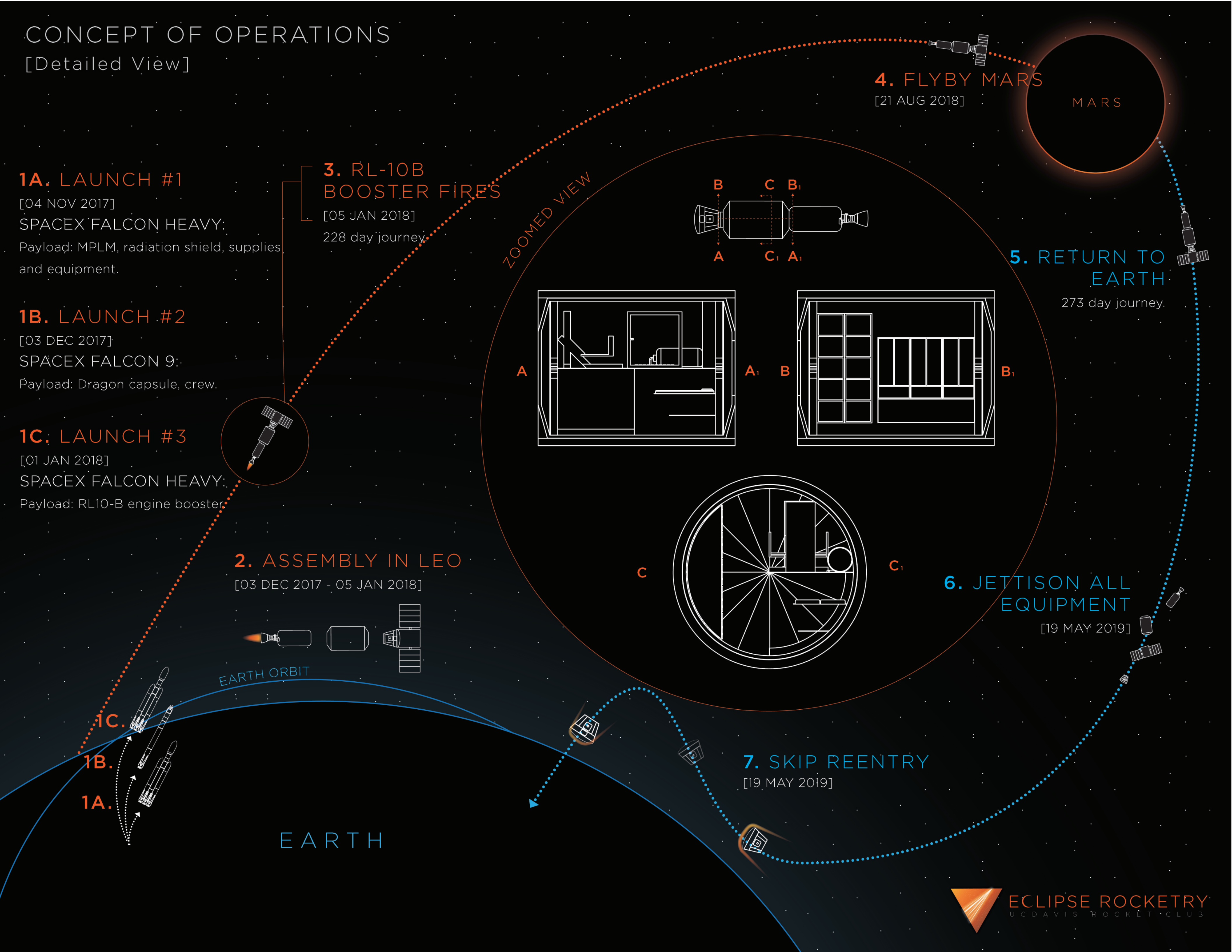
this schedule will be achieved in under $2 billion dollars.

ECLIPSE believes that quality of accommodations is inseparable from crew health and safety. The duration of this mission and novel technologies involved means the crew will play a vital role in maintaining a healthy and survivable environment. It is of the utmost priority that mental strain be eased with a comfortable living environment to prevent the well-documented yet unpredictable mental disorders that such isolation and danger can produce. Moving to the foreign environment of space creates significant biological challenges. Thus, ECLIPSE placed special attention on including biomedical research capabilities that will maximize benefit for future human missions.

ECLIPSE has designed a closed loop life support system in a similar manner to Paragon Space Development Corporation. By first mapping the movement of resources and then selecting specific technologies, an efficient, closed-loop system was designed while minimizing onboard resource storage. Solar flare protection is provided by reconfigurable internal Polyethylene paneling, allowing crew to greatly increase passive shielding orthogonal to a detected solar flare. The SpaceX Dragon command vehicle and RL10B-2 booster will provide attitude control through customized Draco reaction thrusters. Mission control will provide navigation and general communication through NASA Deep Space Network facilities. The power and communications systems are designed for redundancy to ensure reliable contact with mission control.

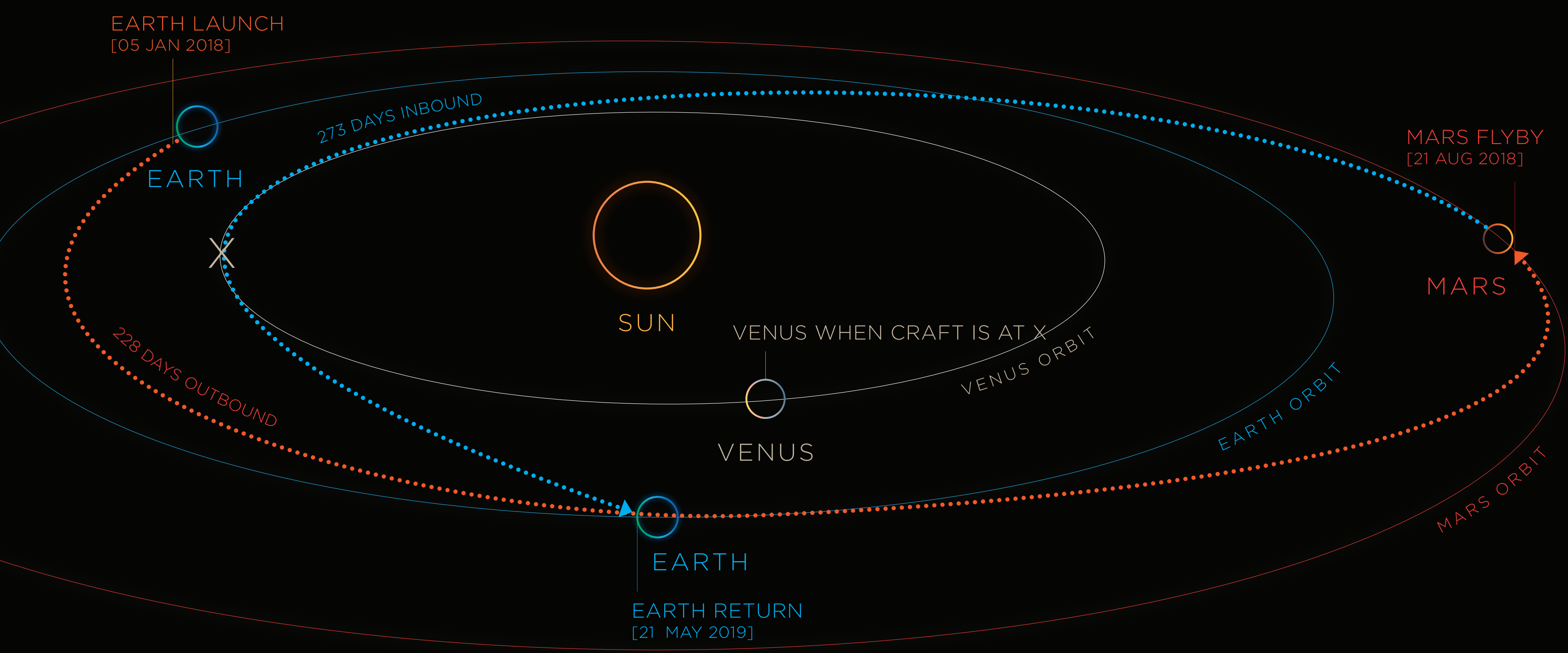
The craft will end its journey with pre-reentry deceleration using a stored booster and a subsequent skip reentry, distributing g-forces through an extended duration. The Dragon will touch down in the ocean after a gentle parachute descent through Earth's atmosphere.

Space is a goal unlike any other.



CONCEPT OF OPERATIONS
[Detailed View]
1A. LAUNCH #1
[04 NOV 2017]
SPACEX FALCON HEAVY:
Payload: MPLM, radiation shield, supplies and equipment.
1B. LAUNCH #2
[03 DEC 2017]
SPACEX FALCON 9:
Payload: Dragon capsule, crew.
1C. LAUNCH #3
[01 JAN 2018]
SPACEX FALCON HEAVY:
Payload: RL10-B engine booster.
2. ASSEMBLY IN LEO
[03 DEC 2017 - 05 JAN 2018]
EARTH ORBIT
3. RL-10B BOOSTER FIRES
[05 JAN 2018]
228 day journey.
ZOOMED VIEW
4. FLYBY MARS
[21 AUG 2018]
MARS
5. RETURN TO EARTH
273 day journey.
6. JETTISON ALL EQUIPMENT
[19 MAY 2019]
7. SKIP REENTRY
[19 MAY 2019]
EARTH
1C.
1B.
1A.
B
C
B₁
A
C₁
A₁
A
A₁
B
B₁
C
C₁
ECLIPSE ROCKETRY
UC DAVIS ROCKET CLUB

CONCEPT OF OPERATIONS
[Trajectory]



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UCDAVIS ROCKET CLUB

Mission Design

Trajectory

ECLIPSE has chosen the 501 day Free Return Trajectory (FRT) first calculated by Patel et. al in “Mars Free Return Trajectories”. This will have a launch date of 05 JAN 2018. An FRT relies solely upon gravitational forces and occasional trajectory adjustments to return the spacecraft to Earth. Due to the shifting relative position between Earth and Mars, there are only certain trajectories that can be considered Free Return. In “Mars Free Return Trajectories”, Patel et. al has utilized computational methods to calculate all possible FRTs over a given time span, which for earth and Mars repeats every 15 years [1]. There are only two of these in each 15 year cycle. There are other, more frequent FRT trajectory options of 2-3.5 years TOF. A 501 day trajectory was selected to reduce the mission duration and the risks and health concerns of the crew. Furthermore, the next 501 day launch window occurs in late 2015 to early 2016, with another following in late 2017 to early 2018. The 05 JAN 208 launch date is selected to give adequate preparation and development time.

The trajectory is broken down into individual events and parameters. Detailed calculations are included in Appendix A. Refer to page two of the Concept of Operations for an illustration of the trajectory path and critical events.

ECLIPSE’s spacecraft will begin in Low Earth Orbit (LEO) and be subsequently propelled onto the Mars FRT. This utilizes a hyperbolic escape, effectively placing the craft on the Mars FRT. This is accomplished by a thruster burn which creates a change in velocity (ΔV) of 3.48-km/s. Figure 2 displays this event, occurring on 05 JAN 2018.

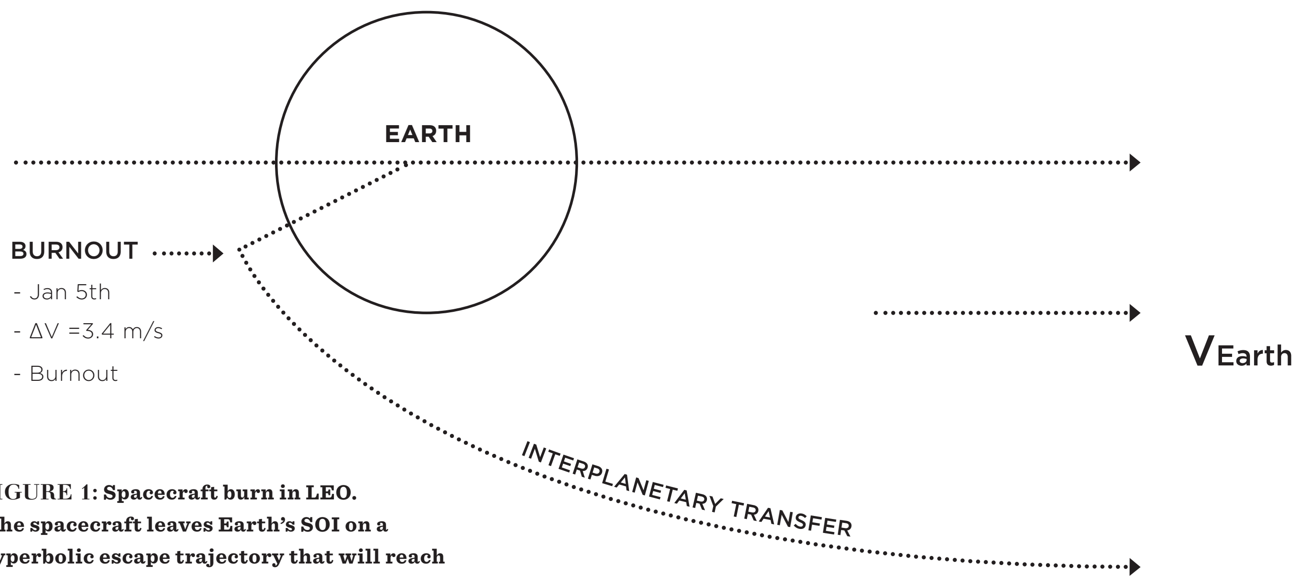


FIGURE 1: Spacecraft burn in LEO. The spacecraft leaves Earth’s SOI on a hyperbolic escape trajectory that will reach Mars after 228 days.

The spacecraft is now in a low energy “interplanetary transfer” from Earth’s orbital path to Mars [2]. This transfer occurs over approximately 228 days; at this point the spacecraft will reach Mars on 21 AUG 2018. It is important to note that Mars would occupy a different point in its orbit at this time with a launch date different from those specified by Patel. This is why the given launch windows are crucial. Launching on 05 JAN 2018 ensures the spacecraft will fly

within a few hundred miles of Mars's surface as the transfer is completed.

At this point, the spacecraft enters Mars's gravitational sphere of influence (SOI), thus changing velocity and direction. This change is essential in placing the spacecraft on an elliptical trajectory that returns it to Earth. The spacecraft travels for another 273 days until reentering the earth's atmosphere at 14.2-km/s on 21 MAY 2019 [3].

In conclusion, ECLIPSE selected the Free Return Trajectory described by Patel et. al for a fly-by of Mars. This trajectory was chosen to shorten flight times and minimize ΔV, ensuring mission simplicity and success.

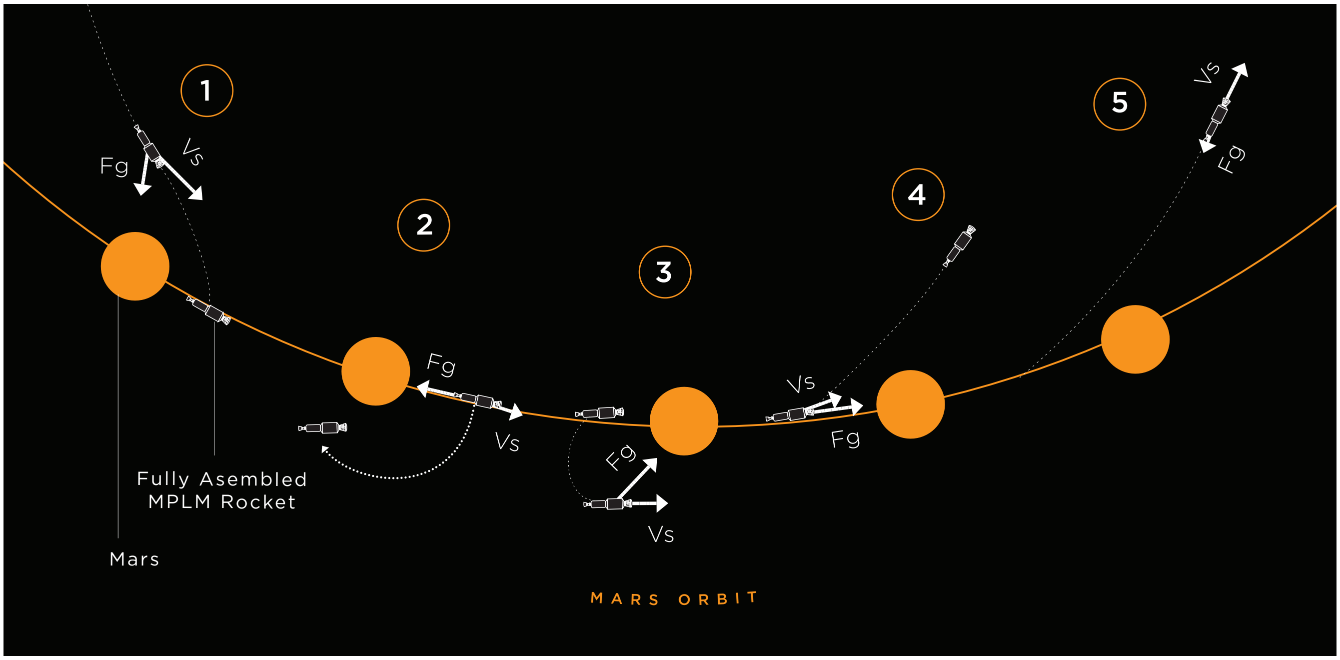


FIGURE 2: Illustration showing the path of Mars flyby.

Spacecraft Design

ECLIPSE has designed a spacecraft assembly through the utilization of tested and cost-effective modules that will meet all mission requirements. First, it must provide enough volume for 501 days of acceptable habitation for 2 astronauts and storage of all Food, Equipment, Supplies and Cargo (FESC). Additionally, it must provide human launch and reentry capability as well as trajectory adjustment capability via reaction control thrusters.

ECLIPSE has concluded that the combination of a command vehicle and a living module will effectively meet all mission needs. Four command vehicles were considered, proportionately accurate sketches of which are shown in Figure 3. ECLIPSE's command vehicle analysis determined that a modified SpaceX Dragon is the most effective selection, due to a combination of technological readiness, cost savings and reduced mission risk. Furthermore, to create sufficient free volume, it will be attached via Common Berthing Mechanism (CBM) to a customized National Aeronautics andSpace Administration (NASA) Multipurpose Logistics Module (MPLM) which will serve as the primary living area. The motivating factors for this decision include minimizing overall cost and mission risk with a focus on flight proven technologies while providing an excess of habitable volume to improve crew comfort.

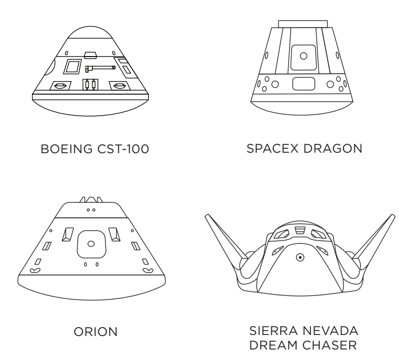


FIGURE 3: Vehicle options to scale

Volume Requirements

Each crew member requires their own habitable volume. ECLIPSE based the interior spacecraft design on the optimal habitable volume recommended by the Celentano curve, shown by the top curve in Figure 4 [4].

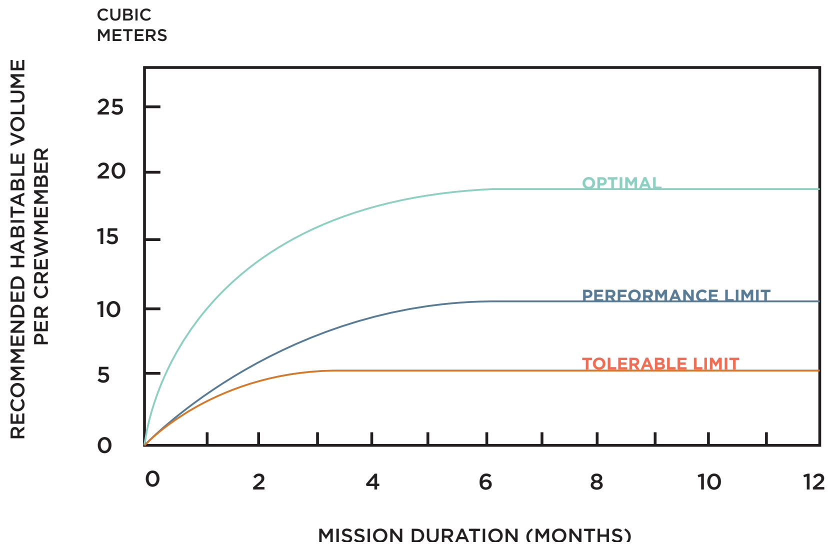


FIGURE 4: A reproduction of the Celentano curve by Martin, Rudek, Miller and Norman describing recommended habitable volume requirements. For mission durations of over 6 months, the optimal volume per crew member is 19.4-m³ [4].

FESC requires significant storage capacity. The specific mission components are itemized in Appendix C. The total volume requirement is 13.4-m³. This includes all necessary equipment for life support, exercise and health monitoring. Imperfect packing and arrangement of FESC in the final spacecraft suggests an allowance for extra volume. 17-m³ is used as a conservative estimate for the free volume required by FESC.

Finally, two 5.2-m³ discs of High-Density Polyethylene (HDPE) must be contained inside the craft. The necessary volumes are shown in Table 1.

	Volume Required (m^3)
Optimal Habitable Volume (2 person crew)	38.8
FESC	17
Internal Shield	4.6
TOTAL:	66.2

TABLE 1: Total internal volume requirements. The three rows correspond to Tolerable, Performance and Optimal levels of habitable volume. 64.5-m³ or greater will provide comfortable liveable volume for both crew members as well as sufficient space for FESC.

Command Vehicle

The main technological contributions of the command vehicle for this mission design will be a central computer interface, launch and reentry, trajectory adjustments and central power management components. Virtually all available manned space vehicles were considered for this mission. The Russian Soyuz is the only manned vehicle in active flight [5]. There are four other vehicles that offer the necessary capabilities and have impending manned certification. The in-development NASA Orion is a high profile and capable option. Three private vehicles being developed under NASA Commercial Crewed Development (CCDev) contracts that are also possible are the SpaceX Dragon, Boeing CST-100 and Sierra Nevada Corp. (SNC) Dream Chaser.

ECLIPSE determined that working with primarily American companies would facilitate fast communication, customization, and scientific understanding. The chosen command module will require extensive mission customization and compatibility with primarily American systems. For this reason, the Russian Soyuz capsule was not further considered. Table 2 shows some basic statistics on the 4 vehicles ECLIPSE considered in detail.

	SpaceX Dragon [6]	Boeing CST-100 [7]	NASA Orion [8]	SNC Dream Chaser [9]
Max Diameter (m)	3.6	4.56	5.01	N/A
Length (m)	3.1	5.06	3.3	9
Pressurized Vol. (m^3)	10	16 *	19.5	16
Unpressurized Vol. (m^3)	14/34 (trunk/extended)	N/A	N/A	N/A
Total Mass (kg)	4900	13000	31408	9000*
Heat Shield	PICA-X	Boeing Lightweight Ablator	AvCoat	Unknown

TABLE 2: Basic command module information, comparing four vehicles that are operational or undergoing certification testing.

***Unofficial or estimated values**

****Unconfirmed for deep space equivalent**

Development Timeline

The NASA CCDev program has sponsored the development of the SpaceX Dragon, Boeing CST-100, and SNC DreamChaser, while the Orion is NASA developed. The objective of this program is to produce a private vehicle capable of U.S. human mission to LEO and International Space Station (ISS), operational by 2017 [6]. ECLISPE has concluded that the SpaceX Dragon is the most advanced in its development cycle and is most likely to be available at launch time. The CST-100 and Dream Chaser will likely be available, but they are behind in their development. The Orion is not scheduled to have its first human test flight until 2021, so it is not realistic for a 2018 launch window [10].

The Dragon is the only option, with real-world testing. It has flown two ISS resupply missions and a high speed 12.5-km/s reentry in the Stardust mission [10, 2]. SpaceX plans its first human Dragon flight in 2015, between two and three years before the chosen 05 JAN 2018 launch date of the ECLIPSE mission [8]. Furthermore, the SpaceX company philosophy and history have demonstrated quick and goal-driven development. This will be beneficial in adapting the capsule to fit the mission requirements.

Launch Compatibility

The launch vehicle must carry the crew members to LEO, where they will stay while the final craft is being assembled. The CST-100 is being designed for usage with multiple launch vehicles (United Launch Alliance Atlas V, Delta IV and SpaceX Falcon 9), adding launch vehicle flexibility[3]. Dream Chaser is currently being designed for the Atlas V [11]; Dragon is exclusively for SpaceX Falcon series launch vehicles [1]. The CST-100 gives ECLIPSE the opportunity to pivot on launch vehicle selection if the need arises. This is the only major factor that differentiates the three in their basic role of ISS transport.

Reentry Capabilities of Command Vehicle

Vehicle reentry will be one of the most dangerous mission segments due to the high return speed of 14.2-km/s. This will generate intense heat and drag forces that can quickly destroy a craft.

The SpaceX Dragon has a significant technological advantage, simply because the craft has already successfully reentered on multiple occasions [2]. Dragon's phenolic impregnated carbon ablator, or PICA-X, heat shield is highly capable, being designed to withstand temperatures experienced during lunar or Martian missions[12]. It is based off of NASA's PICA, which has already endured 2500-°C reentry temperature at a speed of 12.5-km/s, earning it the record for highest speed spacecraft reentry in history [13]; the CST-100 will use the Lightweight Ablator.

The Dragon has a large lead in this critical mission component. Both CST-100 and Dream Chaser would require rigorous verification and testing before ECLIPSE is comfortable utilizing these launch vehicles for reentry.

Command Vehicle Conclusion

The SpaceX Dragon is the most feasible option available to ECLIPSE. Its positive track record, impending manned certification and cost-competitive design will give the greatest chance of success. The CST-100 benefits from Boeing's experience in space design, and is a secondary option if certified in time.

Living Module Selection

In order to meet the optimal total volume of 66.5-m^3, a habitation module must be attached to the Dragon. ECLIPSE considered multiple modules. The Bigelow inflatable modules provided an innovative, cheap and lightweight solution, but were eventually discarded due to internal geometric constraints and development schedule risks (see Appendix B). ECLIPSE settled on the NASA MPLM as the final habitation module.

Living Module Conclusion

The NASA MPLM is a module developed in the late 1990s, initially used as a cargo transportation module in the space shuttle missions. This module's 4.56-m diameter and 6.40-m overall length provide a spacious volume for the mission, approximated in Appendix A as 92.6-m^3. This exceeds the required 66.5-m^3 by a margin of 26.1-m^3. This margin will be important as the ECLIPSE design matures approaching launch date. This allows room for experimental and safety equipment that ECLIPSE has not included in this report, redundant systems and extra supplies. Finally, the mental health of the crew will benefit from a maximum amount of free space. The Celentano curve is a useful baseline but has no representative data on which to base its estimations for long duration missions, necessitating excess space. A drawback to the size of the MPLM is an increased mass in radiation shielding (see Final Design). After balancing crew health, mission simplicity, cost and other factors, this weight penalty was deemed acceptable and the benefits of the MPLM worthwhile.

The module should be configured with a Common Berthing Mechanism (CBM) both ends: on one end for berthing with the Dragon and on the other for mechanical connection with the RL10B-2 booster (detailed in Trans-Mars Injection Burn).

Launch Systems

The proposed launch system was designed to launch the required mission elements onto the trajectory earlier described. ECLIPSE has chosen SpaceX as the launch systems provider due to a combination of high-mass payload to LEO capabilities, as well as industry leading cost structure. ECLIPSE sought to optimize the mission capabilities to utilize the launch vehicles to their maximum potential. A simple on-orbit assembly, as later described, allows for a large spacecraft volume and expanded scientific impact of the mission.

The 501 day mission being considered will require a large amount of FESC, including a wide array of technological equipment, yielding a total mass of 33,500-kg. A large portion of this mass comes from the polyethylene radiation shield that is essential for of the crew's health (see Radiation Shielding). While this high mass system is not ideal, this section outlines a feasible and affordable method for achieving the Mars FRT. Three launches will be necessary to assemble the primary spacecraft in LEO (MPLM, shield, command vehicle, trunk, and booster). The

assembly operations will require a precise schedule with adequate preparation, due to the time-sensitive nature of the launch window. There are several factors to take into consideration when planning the launch dates for this mission, such as potential causes for delays. Additionally, one has to consider the availability and technological readiness of the proposed Launch Vehicle (LV) choice.

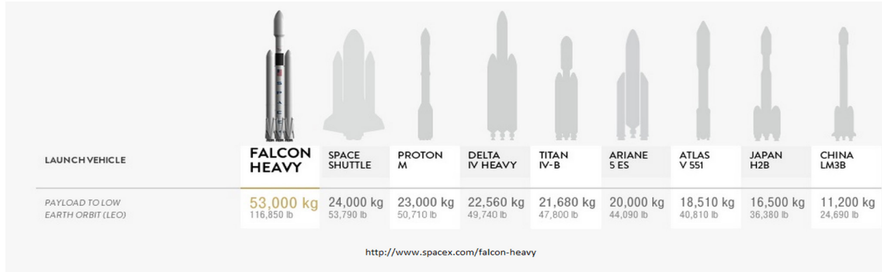
Launch Vehicle Selection

In selecting a launch vehicle (LV), the flow process from *Space Mission Engineering: The New SMAD* was first considered [11]. However, it became clear that a different approach was needed. The selection of the LV became heavily dependent on lifting capabilities, such as maximum vpayload capacity to LEO, of available (or soon-to-be available) LVs. It will be shown that three launches can accomplish the ECLIPSE mission design. Considering the large overall amount of payload mass required for the primary spacecraft (MPLM, radiation shield, FESC and a fueled RL10B-2), several heavy-lifting launch vehicles (HLLVs) were considered, including the Delta IV Heavy, Space Launch System (SLS) and Falcon Heavy (FH). Of these HLLVs, the first is operational while the latter two are in development. Table 3 summarizes the Falcon vehicles' capabilities. Special attention should be paid to the high LEO payload of Falcon Heavy. The SLS has its first unmanned flight test slated for 2017 and first crewed launch in 2021—which does not comply with the schedule constraints [12]. The FH will have its first unmanned test flight sometime in 2014 [13] and should be fully operational in time for the 2018 launch window. It is thus proposed that it be used for the two heavier, unmanned cargo launches (detailed in the proceeding subsection). With regards to the human launch, the Dragon is only compatible with Falcon launch vehicles; since the Falcon 9 is competitively priced and will be certified for human flight in 2017 [14], it is thus selected for the second launch.

Parameter	Falcon 9 [15]	Falcon Heavy [16]
First Stage		
Engine	Merlin 1-D	Merlin 1-D
No. of Engines	9	27 (3 cores of 9)
Fault Tolerance	2 engines	1+ engines
Burn Time	180-s	N / A
Thrust (sea-level)	5,890 -kN	17,600 -kN
Thrust (vacuum)	6,670 -kN	20,000-kN
Specific Impulse	340-s	340-s
Fuel/Oxidizer	RP-1 / LOX	RP-1 / LOX
Second Stage		
Engine	Merlin 1-D	Merlin 1-D
No. of Engines	1	1
Burn time	375-s	375-s
Thrust (vacuum)	801-kN	801-kN
Specific impulse (vacuum)	340-s	340-s
Fuel / Oxidizer	RP-1 / LOX	RP-1 / LOX
Technical Overview / Capabilities		
Mass	506,000-kg	1,460,000-kg
Diameter	3.7-m	11.6-m
Stages	2	2
Boosters	---	2
LEO Payload	13,200-kg	53,000-kg
Inclination Angle	28.5°	28.5°

TABLE 3: **A summary of the Falcon launch vehicles (taken from SpaceX).**

FIGURE 5: Comparison of the Falcon Heavy's lifting capabilities to LEO with other available launch vehicles, demonstrating its relatively high payload capacity [17]



While the fairing dimensions of the Falcon vehicles are not the largest (the Delta IV Heavy has a 19.8-m long, 5-m diameter fairing [17]), it is the lifting capability of the FH that made it the most advantageous choice. The FH will be able to carry more payload to LEO than any other current LV available (shown in Figure 5), which is critical in minimizing the number of launches. As it will be shown, the radiation shield contributes the most to the payload mass of the first launch. The initial shield design caused the payload mass to exceed the FH's current capabilities. Thus, an iterative approach was taken to minimize the shield mass such that the required propellant for the Trans-Mars Injection (TMI) maneuver was optimal, so as to meet the FH's capability as closely as possible.

However, there is the need of expanding the current fairing's diameter (both the Falcon 9 and FH use the same-sized fairing); the diameter of the 1st payload (MPLM + shield) exceeds the current inner diameter of the fairing by 26-cm. As such, it is proposed that the inner diameter be expanded from 4.6-m to 5-m, leading to an outer diameter of 5.2-m (see Cost Analysis section for cost estimation).

Both the Falcon 9 and FH have fixed costs per launch, summarized below. The table does not account for inflation rates and evolving cost structure; it is difficult to determine how different (if at all) SpaceX's LVs will cost to launch three years from now. Regardless, the FH is currently more cost-effective than its competitors, such as the Delta IV Heavy and the Atlas V, being 82% and 32% more expensive, respectively [18, 19]. Table 4 gives the total launch costs per SpaceX LV.

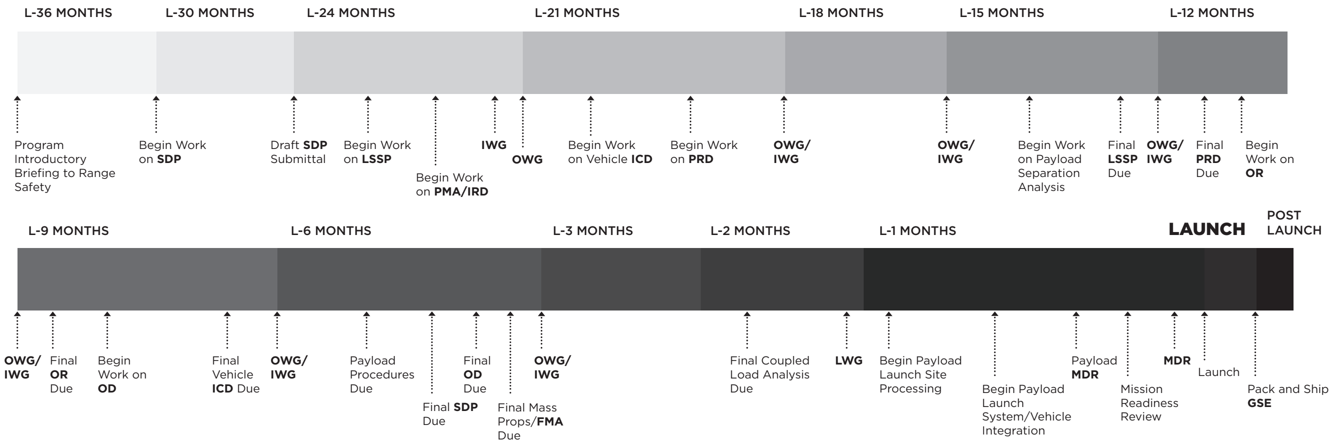
Launch Number—LV	Cost [20]
1—Falcon Heavy	$77.1M
2— Falcon 9	$56.5M
3—Falcon Heavy	$77.1M
Total	$211M

TABLE 4: Estimated total launch vehicle cost (as of 2013). The shown price tag could change by 2017, due to inflation and other factors

Schedules & Operations

ECLIPSE determined that a minimum of three launches is necessary for this mission. Referring to Figure 6, it is reasonable to follow that preparation schedule for all three launch operations. This figure demonstrates the longterm planning that goes into every launch; for this complex mission, launch selection and planning must begin at least 36 months beforehand, or JAN 2015. ECLIPSE proposes the following launch interval guideline (which was applied in the assembly of the ISS): "A minimum of 27 open days between Space shuttle launches must be preserved. This allows adequate launch pad processing time in case of previous flight anomaly diagnosis and for ground processing for turnaround for another shuttle launch." [21]. The interval between launches should be minimized to reduce crew and equipment time in LEO, but this guideline provides adequate time for unforseen delay.

This mission will require the assembly of three major components: the MPLM, Dragon capsule (with trunk), and a booster (discussed later). Three locations for assembly were considered: ground, at the ISS, and at a 28.5° inclination orbit (i.e. launching due east from Cape Canaveral). The first option is impractical; the resulting payload mass surpasses the FH's capacity. The second two options were heavily debated. After considering the advantages and disadvantages of both, tabulated below, ECLIPSE settled on a rendezvous assembly at a 28.5° orbit. Not only is launching from Cape Canaveral at a 0° azimuth optimal for trajectory [22], but the launch site is also routinely used for interplanetary missions [23], as noted in Table 5.



FMA - Final Mission Analysis
GSE - Ground Support Equipment
ICD - Interface Control Document
IRD - Interface Requirements Document
IWG - Integration Working Group
LSSP - Launch Site Support Plan
LWG - Launch Working Group
MDR - Mission Dress Rehearsal
OD - Operations Directive
OR - Operations Requirements
OWG - Operations Working Group
PMA - Preliminary Mission Analysis
PRD - Program Requirements Document
SDP - Safety Data Package

FIGURE 6: **Launch operations timeline, taken from Wertz et al, Space Mission Engineering: The New SMAD [11]. It may not be necessary to follow this three-year schedule for the two unmanned launches, but most certainly for the crewed launch.**

The first launch will contain the MPLM—with all FESC installed and packaged inside—and the radiation shield already installed. The second launch will send the crew, capsule and trunk to rendezvous with the MPLM. The trunk will remain attached to the capsule throughout the mission as it houses the solar panel array and storable RS-72 booster for reentry slowdown (see Reentry). The crew will utilize the interval between their arrival in LEO and the booster arrival to setup equipment and arrange supplies from their launch cargo transfer bags. The third and final launch will send a fully fueled RL10B-2 (see Trans-Mars Injection Burn). This payload will rendezvous and dock with the rear end of the MPLM. The booster, which uses cryogenic propellant, cannot spend too much time in LEO, making it essential that this be the final payload. The launch dates shown in Table 6 account for the proposed 27-day launch window and time to reach the 28.5° inclination orbit, ultimately leading to a booster burn on 05 JAN 2018.

As previously mentioned, the radiation shield contributes a significant amount of mass to the first launch. Figure 7 shows the breakdown of Initial Mass in LEO (IMLEO), prior to the booster burn for the TMI maneuver. The reader should refer to the proceeding subsection for the discussion of the booster's propellant mass.

Assembly Location	Advantages	Disadvantages
ISS	• Assistance from U.S. crew members with preparation of MPLM and system diagnostics prior to TMI booster burn	• Safety concerns and required analyses could delay launches • Large accumulation of cost • Less deliverable payload • Booster has to be launched earlier (poses a boil-off issue)
28.5°Orbit	• Simpler assembly with faster completion rate • Cost is not a factor • SpaceX LV capabilities published for this inclination orbit • Booster's cryogenic propellant won't be in orbit for too long	• Crew has to prepare the MPLM on their own

TABLE 5: **Comparisons between orbital assembly of the proposed spacecraft at the International Space Station and at a 28.5-deg inclination orbit; the disadvantages of using the ISS led to the choice of assembly at the lower inclination angle.**

Launch No.	Payload	Mass (kg)	Launch Date
1	MPLM + Shield + FESC	33,500	10 NOV 2017
2	Crew + Capsule + Trunk	10,072	09 DEC 2017
3	RL10B-2 Booster (wet)	53,900	05 JAN 2018
IMLEO Prior to TMI		125,000	

TABLE 6: **Summary of the three launches in terms of payload, mass and proposed launch date. The 2nd and 3rd launch can take place sooner than shown, to allow for more preparation time prior to the booster burn on 05 JAN 2018.**

As with any mission, there are factors that could potentially postpone the launch date of any of the three proposed launches, such as unpredictable weather and mechanical malfunctions. As the weather can influence the delays on the launching date, mechanical difficulties are often the primary reasons why launches are postponed. If the parts inspectors notice an anomaly, they quickly look and attempt to fix the problem; the fixing time can take from minutes to days [24]. Hence, in order to have all the operations done by 05 JAN 2018, any and all factors ought to be anticipated as causes for delays.

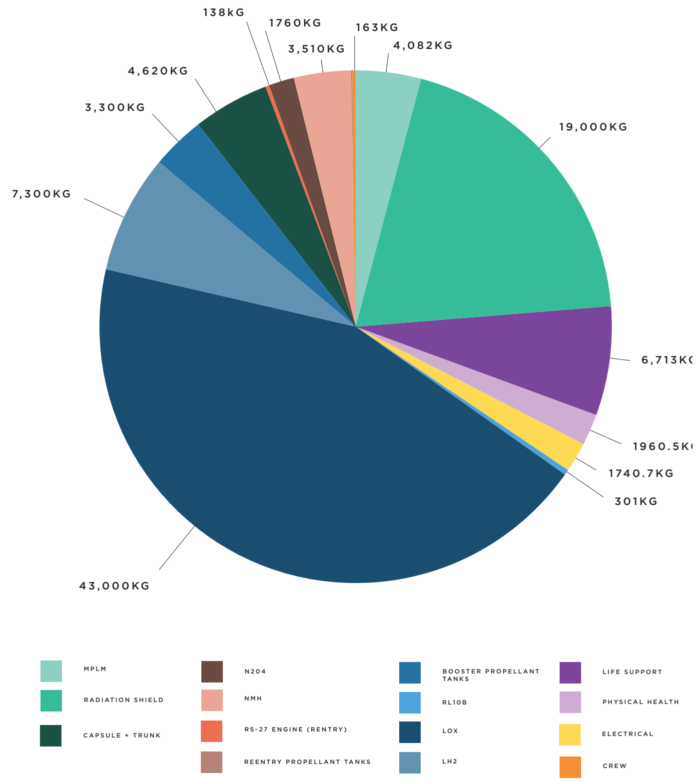


FIGURE 7: The mass breakdown of the spacecraft prior to conducting the TMI burn. Life support, physical health and electrical components make up the FESC for the mission. Note that the crew's contribution is extremely small (the sliver rest between the capsule and MPLM).

Trans-Mars Injection Burn

Once the assembled spacecraft is ready for the journey to Mars, the entire configuration will require a burn for the interplanetary transfer. With a determined ΔV of 3.49-km/s necessary for the transfer (see Trajectory) and given the large dry mass of the assembled spacecraft, a highly efficient booster is needed for the TMI Burn. Table 7 summarizes key specifications of the RL10B-2, which ECLISPE has selected for this burn, with special attention to its vacuum specific impulse value.

Parameter	Value [25]
Length	1.78-m
Oxidizer/Fuel	LOX/LH2
Mixture Ratio	5.88:1
Specific Impulse (Vacuum)	466-s
Thrust (Vacuum)	110-kN
Dry Mass	301-kg

TABLE 7: Key specifications of the RL10B-2 booster. The low dry mass and high vacuum specific impulse makes it the ideal booster for performing the TMI maneuver.

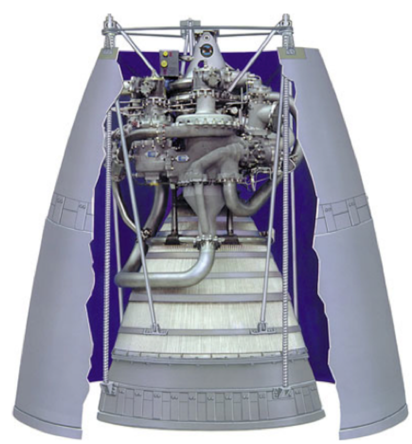


FIGURE 9: The Aerojet Rocketdyne RL10B-2 engine, in its stowed configuration. The extendable nozzle makes it a much more efficient engine [26].

Using the rocket equation and the known parameters of the post-TMI dry mass, ΔV, and the booster characteristics, the following values in Table 8 were determined.

As previously mentioned, the RL10B-2 cannot spend too much time in LEO. By launching the wet booster on the

Parameter	Value
Mass of propellant	50,300-kg
Mass LOX	43,000-kg
Mass LH_2	7,300-kg
Volume LOX	38-m^3
Volume LH_2	103-m^3
Burn time	2,080-s

TABLE 8: **Resulting propellant, oxidizer and fuel mass required for the mission, with corresponding volumes for LOX and LH2. The burn time is large due to large IMLEO.**

05 JAN 2018, boil-off losses should be minimal by the time the booster burn is conducted. To be specific, the burn should ideally take place within a few orbits of the Earth.

The densities of Liquid Oxygen (LOX) and Liquid Hydrogen (LH2) yielded the required volume of oxidizer and fuel. These values will require tanks specifically manufactured for this mission. Using the value for expanded fairing diameter as a reference, approximate tank dimensions were produced (see Table 9). The total length of these tanks and the RL10B-2 in its stowed nozzle configuration is approximately 9.87-m; the configuration is within the published available height inside the SpaceX fairing.

Parameter	Tank Height (m)	Tank Outer Diameter (m)	Tank Inner Diameter (m)
LOX	2.16	4.66	4.65
LH2	5.93	4.66	4.65

TABLE 9: **Estimated tank dimensions for corresponding mass and volume of LOX and LH2 for the mission.**

The tanks will have to be encased, using the same material as the propellant tanks (Al 2195), for subsystem integration and assembly purposes, as well as attaching the payload to the HLLV's payload adapter.

ECLIPSE deems the proposed launch systems and operations to be at their optimal configuration. The payload mass of third launch is slightly over the listed FH payload capacity which can be adjusted to account for as the mission takes a more concrete form. The proposed launch dates are merely based off an ISS assembly guideline; the dates can be changed to more favorable ones (i.e. smaller launch interval) if circumstances allow, and only if the booster burn can still take place on the 05 JAN 2018.

Radiation Shielding

One of the most important challenges for long-duration missions beyond low-Earth orbit is shielding against radiation. Without the protection of the Earth's magnetosphere, the crew, craft, and equipment will be subjected to high doses of radiation from all spectra. Especially dangerous are high atomic number, high-energy particles (HZE). HZEs pose a significant threat to the health and safety of the crew.

To combat these high levels of radiation, both passive and active shielding must be considered to provide sufficient protection while simultaneously adhering to reliability, mass, volume, and energy considerations. Therefore, ECLIPSE recommends a novel use of both active and passive shielding to afford the highest level of protection to the crew and spacecraft. In designing the recommended radiation shielding system, ECLIPSE sought to minimize crew and spacecraft exposure, to reduce overall mission complexity, and to provide a dynamic system capable of protecting the vessel against the stronger solar particle events (SPEs). The passive system, as later described, is a highly reliable, passive system requiring no crew input and has no mid-mission failure capability.

Similarly, the active system is included for recommendation to improve vessel protection and to facilitate further human long duration spaceflight. The moveable passive shielding system described is recommended to provide extra radiation shielding in the case of SPEs. Overall, the radiation shielding system proposed by ECLIPSE provides

complete radiation protection for the mission with reliable systems. The combination of these technologies satisfy the BEIR recommended maximum total exposure of 600-mSv.

There are two types of radiation that present problems to interplanetary travel: galactic cosmic rays (GCRs), SPEs. Both are ionizing. GCR's are the most dangerous type of radiation in deep space. They have intense speed and composition, with energies ranging from 100-MeV to 10-GeV. One percent of GCR's are HZEs (Atomic number (Z)>2, and high Energy (E)) [27, 28], while only a fraction of a percent of SPEs are HZEs. GCRs are particularly damaging to the human body and increase the risk of cancer as they destroy cells and cause single and double-strand breaks in DNA, as well as associated base damage [29]. GCRs are created by interstellar supernovae and come from all directions equally.

SPEs are caused by solar flares and/or coronal mass ejections (CMEs), meaning they always travel radially relative to the Sun. During a solar event, large amounts of protons, and occasionally helium and HZE ions, are released. The magnetic fields created by moving particles can help reduce the flux of cosmic radiation in the solar environment. Solar events prevent the risk of acute radiation exposure from GCRs, but are unpredictable and merit a flexible shielding response to account for SPE spikes. These particles may reach the Earth in two hours or less than 30 minutes, and are unpredictable in the short-term [29].

Besides these primary sources of radiation, there are also other forms of radiation that are problematic in interplanetary travel. These include Bremsstrahlung, Gamma rays, X-rays, and other secondary radiation resulting from collisions and deflections between charged particles.

Radiation Shielding Standards

Standards on exposure are not universal, and agencies disagree with the definition of acceptable risk. The NASA limit for career radiation dosage is a 3% increase in probability of Radiation Exposure Induced Death (REID), or fatal cancer, within a 95% confidence interval. The ESA career limit is a 5% increase in REID or 1000-mSv career dosage [30]. Statistically, an increased risk for cancer begins at 100-mSv/year and lens opacity risks increase beginning at 150-mSv. Many agencies have career dose limits for blood forming organs and the heart at 500-mSv for 1-year missions, which is an applicable baseline limit for a 500-day mission.

Some low dosage health problems are very manageable. Radiation shielding is naturally imperfect and must be simply optimized to maintain a reasonable level of crew safety. The age of the crew is an important consideration as older individuals can be exposed to higher levels of radiation, demonstrated by Table 10. Deviations from perfect shielding are justifiable. Selecting the age of the crew will reduce the risk of REID and, by extension, increase the safety of the mission. Career effective dose limits based on age and sex has been evaluated by NASA and other agencies to predict the limits deep-space 1-year missions [30]. NASA-STD-3001 Volume 1 outlines the relationship of dose-to-risk for crew members on a one-year mission, and can be seen in Table 10 above, providing an idea of how age relates to an extended exposure dosage. In addition, STD-3001 establishes that an older crew selection will significantly reduce REID risk, and females should be at least 40 years to be eligible for the mission.

Age	Males	Females
25	520 (15.7)	370 (15.9)
30	620 (15.4)	470 (15.7)
35	720 (15.0)	550 (15.3)
40	800 (14.2)	620 (14.7)
45	950 (13.5)	750 (14.0)
50	1150 (12.5)	920 (13.2.)
55	1470 (11.5)	1120 (12.2)

TABLE 10: E(mSV) for 3^ REID (Ave. Life Loss per Death, yr). This table from STD-3001 shows career effective dosages in mSv that result in a 3% REID , the NASA effective dosage limit [29].

The Mars Society indicated a dosage limit 600 mSv (Rules - The Mars Society). Considering the above information with other 500-mSv long-term exposure limits and our 501-day journey, adopting a 600-mSv limit as our standard is a safe mission design goal with reasonable reduction in health risks.

Passive Shielding

Passive shielding refers to material known to absorb or break down high energy particles, slowing or stopping them before they can damage the craft or the crew. There are several parameters to consider: mass and volume restrictions, feasibility, optimization, maintenance, and reliability. Passive material shielding plays a vital role in the ECLIPSE shielding design. Aluminum, polyethylene, water, and liquid hydrogen are materials often studied for this purpose. Aluminum aside, these materials are hydrogenous and have high atomic density, resulting in a high number of collisions with incoming particles. Passive shielding is highly reliable, well documented, and requires no extra power generation.

Referring to Figure 10, liquid hydrogen provides the best protection against cosmic radiation. Liquid hydrogen, although ideal, is physically difficult to contain and to keep in liquid state, resulting in the degradation of its shielding qualities. Expensive research and development still needs to be done for this to be feasible. ECLISPE, instead, has chosen high-density polyethylene (HDPE) for passive shielding. HDPE is easily purchased and manufactured, and has been researched for shielding applications by the NASA Langley Research Center [31].

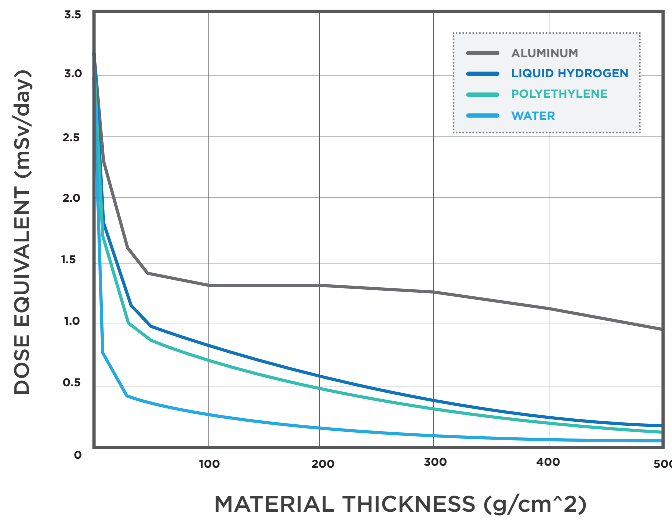


FIGURE 10: Graph demonstrating effective reduction in radiation dose equivalents with increasing material thickness, desired levels are below 0.9-mSv/day. Polyethylene is the second most effective material behind the volatile Liquid Hydrogen [8]

Active Shielding

Active shielding utilizes electricity to create a reflective field that interacts with particles, causing a force on the particle. This force can be used to divert harmful radiation. Two significant types of active shielding that ECLIPSE has considered are electrostatic, which relies on the repulsive force between charged particles, and electromagnetic, which relies on the force created by motion of a charged particle through a magnetic field. Electrostatic can be compared to the force created by spring displacement, while electromagnetic shielding may be compared to damping in that it resists motion.

Electromagnetic Shielding

Magnetic fields are created whenever current passes through a wire. Moving radiation particles create their own magnetic field by the same concept. When these fields interact, a force is created and the particle changes path. It is theoretically possible to create a magnetic field around a spacecraft using a wire coil geometry that will shield the internal region. This concept, however, has multiple challenges. First, resistive losses over extended periods will make the power consumption of the shield unreasonably high. New advances in high-temperature superconducting materials, particularly the ceramic, $YBa_2Cu_3O_7$, can, in theory, super-conduct (negating resistive losses)

without the need of expensive cryogenic cooling [32]. A more serious problem is creating an appropriately shielded geometry inside the coils. The field created by the coils is not a pure dipole, leading to a shielded toroidal region and an unshielded central axis [33]. There are no electromagnetic shielding designs that are universally supported by the scientific community. The underdevelopment of this technology precludes electromagnetic technologies for application in a 2018 launch date, although its potential for promising solutions is high. Development in this field should be closely monitored for progress.

Electrostatic Shielding

Electrostatic shielding relies on electric fields to apply a force to the charged particles that enter the craft's proximity. Similar to electromagnetic shielding, there are no promising designs that can be easily translated to this mission. Various models for this type of shielding have been proposed, commonly in the form of oppositely charged spheres that will produce an electrostatic field between themselves. For any particle of charge q (eV), the potential of the electrostatic field is linearly dependent on the potential difference V (volts). With a sufficiently large V, 100% of charged radiation particles will be diverted from the shielded region—in this case the crew's living quarters. To achieve this effectiveness, however, requires immense potential difference, which can be dangerous and hard to create. The charged sphere designs, such as that proposed by Tripathi in 2008, rely on configurations with unstable equilibrium; any disturbance will result in an attractive force imbalance between the spheres and catastrophic failure. Electrostatic is under-tested, with no directly applicable designs proposed to date.

ECLIPSE has, instead, created a custom design that will utilize electrostatic fields to augment the existing polyethylene shield. The current model proposed would shield a majority of the ship through concentric cylinders, acting as a capacitor and augmenting the already effective HDPE shield with the addition of minimal weight. For any particle of charge q (eV), the potential of the electrostatic field is linearly dependent on the potential difference between the cylinders V (volts).

$$PE=qV$$

However, the required voltages would be on the order of millions of volts in order to achieve full protection with current parameters and may not be feasible (see Appendix D). Any fraction of this voltage, however, would act as a dampener for incoming particles and increase the effectiveness of the passive shielding.

The side-effect of using electrostatic shielding is that, according the laws of energy conservation, reducing kinetic energy of incoming particles must release energy in another form. This energy takes the form of Bremsstrahlung radiation. Bremsstrahlung radiation is the release of a photon due to the change in kinetic energy of the slowed particle. The wavelength of this photon can vary due to the amount of breaking that occurs. Effects of photon radiation, however, is more widely known than compared to the effects of GCRs, making it easier to deal with via conventional methods.

ECLIPSE proposes adding concentric plates to the interior and exterior of the cylindrical HDPE shield. We would charge the concentric plates to high voltage on the ground prior to lift off, creating a strong electric field that does not require energy from the ship to sustain. By embedding the concentric plates a small distance into the HDPE, the danger of an accidental discharge is reduced.

Radiation Shielding Final Design

The crew will spend their time exclusively in the MPLM. The shield design must be cylindrical, surrounding the MPLM. The formula for volume of this geometry is:

$$V_{shield} = \pi(r_o^2 - r_i^2)l + 2\pi r_{inside}^2(r_o - r_i)$$

Where, r_o is the outer shield radius, r_i, is the inner shield radius (also the radius of MPLM), l is the length of the MPLM, and r_{inside} is the inside radius of the MPLM. The shield thickness is given by $(r_o - r_i)$. The volume and mass of HDPE will increase by the square of r_o.

The first step in designing an effective shield was material selection. As previously mentioned, ECLIPSE chose HDPE for its passive shield material. Table 11 shows a diminishing return in decreases of effective dosage as shield thickness increases. ECLIPSE was limited by launch vehicle mass capability, and therefore designed the radiation shield mass to maximum FH payload capacity. ECLIPSE selected a few shielding values, iterating for overall mission dosage received in an effort to keep mission exposure below 600-mSv, while adhering to weight considerations for current launch vehicle capabilities. This led to a passive HDPE shield of .153-m in depth, with final dimensions of , r_o=2.43-m, r_i=2.28-m, l=6.4-m. This shield design will surround the entire MPLM and reduce effective dosage to 598-mSv. LEO has radiation levels of 50-mSv per year, resulating in 3.7-mSv during the 22-days before departure, totaling radiation exposure to 602-mSv [34]. While radiation standards vary wildly and individual biological reaction cannot accurately be predicted, the sum of available knowledge has led ECLIPSE to believe 602-mSv is a survivable limit with manageable health effects.

This design also calls for an arrangement of HDPE to be inside of the MPLM, providing axial and reconfigurable shielding. The blocks will assemble to form disks that shield the spacecraft's axis, also at a thickness of .153-m. These blocks come in 12 uniform slices for each end of the capsule, arranged radially. These slices can be reconfigured to be between the Sun and our crew to shield from unilateral radiation spikes from SPE. Current monitoring techniques are not adequate enough for advanced warning for this mission [35]. An on board particle monitoring system can only recognize an SPE once it reaches the craft and will warn the crew immediately of this occurrence. The crew will need to act quickly to reconfigure the internal shielding in order to protect themselves from the bulk of the SPE, which can last several days [30].

The installment of the blocks will mark the final moment of direct visual contact with our travelers before the inter-planetary journey begins. Total mass of the shielding is 19,000-kg, maximizing the FH launch vehicle's lifting capabilities in combination with the rest of the payload. For future missions, the SLS should be considered with its larger fairing and increased lifting capabilities allowing for a more protected shield, critical in longer journeys (assuming no breakthroughs in active shielding technologies). The estimated cost of an HDPE shielding is estimated $500,000 for total production of the shield.

ECLIPSE can potentially increase the effectiveness of our design with two optional additions. The first makes use of water-lined sleeping bags during time spent sleeping to protect against radiation, or a cylindrical container that can double as a water storage unit. The second addition utilizes the passive shielding as the dielectric between two conducting cylinder plates for an electrostatic capacitor shield. These cylinder conductors would be slightly embedded into the inner and outer surfaces of the HDPE cylinder in order to insulate them. Charge of the capacitor would be attained prior to launch. A capacitance per unit length needs to be larger than 943-pF/m to stop particles the size of an iron nucleus travelling half

Mass per area (g/cm^2)	Depth (cm)	Effective Dose (mSv/day)	Days to 600mSv limit	%Relative Reduction
5	5.31	1.46	409	20.31%
10	10.6	1.28	467	30.26%
14.4	15.267	1.198	499.5	35%
20	21.3	1.08	553	42.28
30	31.9	0.996	602	45.90%

TABLE 11: Tabulated calculations showing diminishing benefit in increasing shield thickness. Data calculated using modified excel sheets from NASA Langley [8]

the speed of light (see Appendix D). Further necessary research would include studying the sum of the shielding effects provided by both methods actig simultaneously. The radiation assessment detector (RAD) is included to aid in the study (see Appendix J). Material selection for the capacityor should be studied to allow for the highest possibe potential difference.

A final summary for the design calls for a baseline passive shield augmented by a concentric capacitor and extra internal shielding. A 0.179-m thick HDPE cylinder will reduce exposure to 602-mSv over 501 days. The novel electrostatic shielding concept proposed above could significantly reduce this exposure as a function of potential difference, which cannot be reasonably estimated until further development. Taking advantage of time spent sleeping, water lined sleeping bags that double as water storage will further reduce exposure. This combination of technology has redundancy in reducing exposure, and therefore maximizing mission success.

Reentry

As any spacecraft moves from the vacuum environment of space to Earth's atmospheric environment, significant energies are generated. Reentry spacecraft are designed to counteract these energies. The most significant are thermal and kinetic energies. A given spacecraft can withstand a maximum temperature before structural compromise. Total heat flux is also a concern, as long duration reentries can lead to damage to internal components that are not designed for high temperature operation. The change in kinetic energy imparted due to atmospheric drag creates G forces, which can cause damage to craft and crew. Different reentry conditions, like velocity, angle of entry and vehicle characteristics like mass and cross section determine reentry performance. Different reentry methods will change the reentry time duration, which affect the balance between heating and g forces.

In determining the most effective reentry strategy, crew health, safety and heat management were determined to be the utmost priorities. A skip reentry, as is later described, was selected as the optimum balance of the two constraints. The safest reentry is facilitated through the use of a stored booster, reducing effective reentry speed. This method subjects the crew to a minimum of harmful accelerations and does not detract from the operability of the overall mission.

Reentry Methods

The two possible direct entry models that ECLIPSE discusses are ballistic and skip reentries [36]. Ballistic reentry is the most basic reentry type, and is simply a direct trajectory to the planet's surface. It has a low time duration and sees high maximum temperature and g-forces but low total heat flux. Skip reentry, or lifting reentry utilizes multiple skips to extend the time duration, ending in a final ballistic reentry. This reduces maximum temperature and g-forces but increases total heat flux. Figure 11 illustrates the skip reentry process.

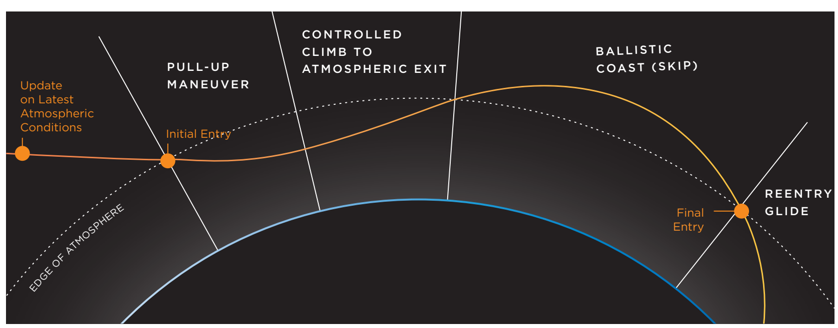


FIGURE 11: Skip Reentry, showing two skips. Due to the dynamics of atmospheric skip, this is usually a two skip process. Enough velocity is lost in the first skip to allow a ballistic reentry in the second.

A potentially useful orbital process is aerocapture. The spacecraft grazes the atmosphere on initial pass, creating some drag and change in velocity which places the spacecraft into an orbit around earth, effectively "capturing" it. From this point, the space-

craft can be gradually reduced in velocity using further grazing until a manageable speed is achieved for final entry [26].

Final Reentry Selection

The physical condition of the crew will be degraded after 501 days of microgravity. The Physical Health subsection has determined that, in order to maintain musculoskeletal integrity, g-forces must be absolutely below 8-g's, with less than 6-g's preferred. It will be shown that velocity must be reduced to provide any safe avenue for reentry.

Referring to Trajectory, the spacecraft will be returning to earth at approximately 14.2-km/s. ECLIPSE has calculated maximum g-force for ballistic reentry to be 57.8-g's — over 7 times higher than the maximum acceptable limit of 8-g's. Temperature generation will not be a limiting factor in this scenario, as the Dragon craft has already survived temperatures of 2770-K at a velocity of 12.9-km/s. [37] Table 12 below lists g-forces for all ballistic reentry velocities between 1 and 14.2-km/s, showing that the first acceptable reentry velocity occurs at 5-km/s. Ballistic entry requires a $\Delta V = 9.2 - km/s$ from Middle Earth Orbit.

velocity (km/s)	g forces
1	0.295
3	2.65
5	7.37
7	14.4
9	23.8
11	35.6
14	57.8

TABLE 12: g-forces for ballistic reentry at a variety of velocites. The first velocity condition that reduces g-forces to less than 8 g's is 5km/s drastically lower than the return speed of 14.2km/s.

Skip reentry reduces the g-forces felt by extending the total duration. The deceleration forces will be felt for a longer time, but to a lower magnitude. In Appendix E, the equations of motion for the capsule in skip reentry are shown, and are used to calculate the flight path of the capsule as it reenters the planet [38, 39]. ECLIPSE generated velocity and flight path data for various reentry speeds. Two major scenarios are observed in Table 13. At higher velocities, the capsule performs one skip and continues past earth, entering into a highly elliptical orbit (aerocapture) or missing earth orbit entirely. Aerocapture would extend the reentry timeline, placing further strain on life support and crew, and is thus avoided. Below 11.8-km/s, the capsule enters a second time and returns to the earth's surface, completing the 2-skip reentry.

velocity (km/s)	g forces 1st skip	g forces 2nd skip
14.2	2.44	NA
13	2.36	NA
12.2	3.22	NA
12.1	3.09	NA
12	3.7	NA
11.9	4.07	3.06
11.8	5.43	3.72
11	4.07	2.08

TABLE 13: g-forces for skip reentry at various velocities, calculated using a graphical user interface (GUI) from the Air Force Institute of Technology [38].

Note these scenarios do not account for pilot input; with major pilot input, a skip reentry of 14.2-km/s is possible. By the end of each skip the pilot would roll the capsule in such a way that the lift vector would cause the capsule to reenter and perform another skip until the velocity of the capsule is able to safely approach the earth's surface.

It is possible to change the lifting characteristics of the capsule with a vehicle modification rather than a complete redesign. A greater lift to drag ratio means the capsule is more maneuverable during reentry [37]. This would be done by adding an asymmetric flap layered with the heat shield to the base of the Dragon capsule. This flap would increase the effective sidewall angle of the capsule, forcing the capsule into an orientation that generates greater lift in the direction of flap. This flap must be structurally robust and would likely incur sig-

nificant development cost. The longer duration of this technique would significantly increase total heat flux and necessitate additional heat sink material between PICA-X shield and the interior aluminum walls.

Paraffin can be used as a phase change material (PCM), which has a high latent heat of fusion. Paraffin heat sinks work by absorbing heat until they reach their melting temperature at which point the heat absorption remains at a constant temperature. The advantages to using paraffin include its light weight, thinness, and high heat capacity; a disadvantage is that if the microbags are punctured paraffin is highly flammable [38]. The company ESLI has proven that paraffin is a space worthy heat sink with its implementation in the space shuttles [39]. Implementation to the Dragon capsule requires research to compare benefits and cost of adding a paraffin layer to increasing the thickness of the aluminum sidewalls.

While a piloted reentry may be plausible, ECLIPSE believes the exponentially higher total heat absorption poses serious risk of capsule compromise. Instead, installation of a storable booster will provide ΔV=2.4km/s, allowing for a safe, self-guiding 2-skip reentry. The reentry data is displayed in Table 13.

In order to perform a successful skip reentry, the spacecraft must achieve ΔV=2.4-km/s. Various flight path scenarios are shown in Figure 12. Figure 13 shows the velocity change versus time which is used to show the g forces felt by the crew. These reach a maximum of 5.4-g's at V=11.8km/s, acceptable under the conditions defined by Physical Health.

Final Reentry Design

As the spacecraft approaches within 1 day of reentry, the crew will transfer adequate supplies and equipment from the MPLM to the Dragon spacecraft. The Dragon will then separate from MPLM and RL10B-2 motor, reducing mass to approximately 5000-kg (see Appendix E).

In order to achieve the selected skip condition of V=11.8-km/s, ECLIPSE will perform a pre-reentry burn using a booster based on the Rocketdyne RS-72 engine. This engine uses non-cryogenic propellants and was selected due to its class-leading ISP value. This liquid engine utilizes Nitrogen Tetroxide and Monomethylhydrazine (N_2O_4 and MMH), with ISP=340-s. It measures 2.28-m in length and 1.30-m in diameter [43]. The reentry burn will require 5270-kg total propellant mass. With a mixture ratio of 2:1 (N_2O_4:MMH), volume is calculated as V_{N2O4}=3.65-m^3 and V_{MMH}=5.99-m^3. In order to properly store the propellant tanks and the engine the Dragon trunk must be extended to an outer length of 5.8-m. This lengthening should have manageable effect on launch dynamics and properly protect the booster through launch and assembly. Refer to Appendix E for detailed calculations.

Communications

Communication systems provide the connection between the spacecraft and Earth and allow for transmission of critical and scientific data. The communications system was designed to meet criterion defined by mission requirements for scientific integrity, enabling emergency communications, and facilitating personal contact as described in the Mental Health subsection. ECLIPSE recommends an onboard system based on Mars Reconnaissance Orbiter (MRO) hardware. When paired with the Earth-based NASA Deep Space Network (DSN), the communication system meets mission requirements at low cost with high reliability.

Data Requirements

ECLIPSE's communication group allots the mission weekly text communications, bi-weekly picture communications, and monthly video uplink communications. The minimum recommended communication for the crew should be about 500-Mb of e-mails and pictures approximately once per week (250-Mb of information per crew member)

and about 1-Gb video (roughly fifteen minutes) once every two months [44].

In contrast, mission control communication will require relatively small data transmission. Uplink (from Earth to the spacecraft), will consist of trajectory adjustments, software updates, text instructions and voice messages. Downlink (spacecraft to Earth), will consist of mission diagnostics, equipment data and response messages. Video and pictures, the most bandwidth intensive types of data, are unnecessary in communicating with mission control.

The detailed dates of communication and special occasions are mentioned in Appendix F.

Communication from Earth: The Deep Space Network

The NASA DSN is the premier deep space communication facility, that provides continuous coverage from three locations around the world [45, 46]. One of the main challenges of deep-space communications is distance. The intensity of electromagnetic radiation decreases in proportion to the square of the distance, so signals from deep-space probes are usually very weak when they reach the Earth [47]. Large 70-m parabolic disc antennas are used to collect as much information as possible from the spacecraft [48]. Based on the expected signal decay and expected communications schedule, the cost and availability of the DSN was determined, as described in Appendix F.

On-board Communication: Modified MRO Platform

A customized version of the MRO hardware will be installed onto the spacecraft. MRO hardware is the most advanced communication system and will be cost-effective in achieving the mission objectives.

The MRO carries three main instruments for communicating and navigating. The *Electra Ultra High Frequency Communication and Navigation Package* enables the spacecraft to act as a communications relay between Earth and landed rovers on Mars. It also helps determine its distance and speed in relation to Mars [49]. The *Optical Navigation Camera* will enable improved navigation capabilities. Finally, the *Ka-band Telecommunications Experiment Package* uses significantly less power, increases the spanned bandwidth of the downlink signal, and reduces the effects of charged particles on signal propagation.

Aside from these main instruments, the MRO has three antennas, three amplifiers, and two main transponders [50]. One 3-m diameter Ka band antenna sends and receives data at high rates, and two X band antennas provide lower-rate communication during emergencies and special events [53]. Two Traveling Wave Tube Amplifiers will act as the mission signal amplifiers [53]. In addition, two transponders will be included, one main and one backup [51].

All of these components have to be integrated into the central computing system of Dragon capsule.

Ongoing Research: NASA LCRD and Phased Array Antennas

NASA's Laser Communications Relay Demonstration (LCRD), is a new technology currently under development and testing. It has recently passed a major milestone in a technical demonstration involving the Lunar Atmosphere and Dust Environment Explorer, a satellite in lunar orbit. This technology promises to increase communication speed 10 to 100 fold over standard radio frequency (RF) transmitter methods [52]. NASA claims that these returns could be even higher, stating that current receiver technology is the bottleneck rather than the laser potential. The fundamental science behind laser communications, like any communication, has to do with wavelength. A shorter wavelength means a higher frequency, and a higher frequency means more data. RF communication technologies have been steadily increasing in frequencies in order to increase information. This new laser communication system promises to be the next step in the quest for ever-higher frequency. The potential data rates are very high with such huge frequencies. Further technological developments with LCRD technologies are recommended to be observed until the launch date for possible inclusion of the technologies.

Phased array antennas are currently upgrading many conventional antennas in the communications field, including the DSN [50]. Antenna arraying refers to the use of multiple, smaller antennas working together, in place of a single large antenna. This method of antenna realization is advantageous to the mechanical method because of reliability.

Power System

The ECLIPSE power system was designed with a significant margin of safety to reduce mission risk. The recommended solar system will utilize many components already installed on the Dragon, reducing system cost and ensuring a simple development cycle.

Power generation for all ECLIPSE systems will be accomplished with solar generation. The average ECLIPSE power consumption totals at approximately 7-kW, with the breakdown detailed in Appendix G . ECLIPSE designed a system that would provide 8-kW or greater at all points in flight to account for consumption peaks and other variability.

A power system considered was the Radioisotope Thermoelectric Generator (RTG). RTGs utilized the natural radioactive decay of non-weapons grade plutonium that generates heat, which can be converted to DC electricity using solid state thermo-electric converters. RTGs are a reliable, stable, and safe system [55]. However, current RTG designs can only produce 110-W [56]. This would mean that about 70 RTG units would be necessary to supply the space craft with its required power. Each RTG weighs about 45-kg, therefore the RTG power system would weigh over 3150-kg [57].

Solar panels, on the other hand, take advantage of conversion from electromagnetic waves produced by the Sun. The totality of the ECLIPSE solar design, detailed in Appendix G, weighs just over 2020-kg, making it significantly lighter than an equivalent RTG system [58]. Furthermore, because the Dragon capsule is already configured with a solar system, many of the existing components can be utilized with expanded solar panels. This allows for greater generation while saving cost.

Solar generation brings a couple issues. First, the solar eclipse that occurs as the spacecraft passes behind Mars will cause a 20 minute lapse in generation. Rechargeable batteries will supply power during this outage. Another issue is in properly orienting the cells. Maximum power output occurs when the panels are perpendicular to the incident solar rays. This system must be adjustable to ensure orthogonality. Lastly, electromagnetic wave intensity, and thus solar power generation, is proportional to $1/r^2$, where r is distance from source. This solar system is designed to produce sufficient power at its maximum distance from the Sun when it flies by Mars.

An important design note is the available interaction between the power channels from each wing. For the sake of safety, the solar panel system will be designed with redundancy between channels, allowing for one channel to compensate for an outage in the other. In the case of a malfunctioning piece of equipment in one channel, the crew will still be able to survive by sharing the other power channel.

Final Power Design

The Dragon capsule's standard solar system produces between 1.5 and 2.0-kW [59]. This system will be upgraded to meet mission power requirement. The primary upgrade is in solar panel size.

ECLIPSE will utilize solar panels manufactured by Spectrolab, the company that was subcontracted for the ISS solar panels. The ISS runs solely off of solar power with one wing producing 20.9-kW of power at an array area of 776-m^2, which equates to 0.027-kW/m^2 [58]. ECLIPSE utilizes these panels, produced by the manufacturer Spectrolab, as a parallel in designing our system. Since manufacturing the ISS system, Spectrolab's panels have increased in efficiency by 175%. This means they now produce 0.074-kW/m^2. To meet the 8-kW power requirement at Mars for ECLIPSE's craft, this equates to 209-m^2 of solar panels. The final system design will be 2 wings with the

dimensions 5.8-m x 18-m. The solar power system will generate a minimum of 8-kW, with higher generation at all points of the trajectory closer to the Sun.

The Dragon capsule already has solar infrastructure in place to support the proposed panel expansion. Certain components may require modification to support higher wattage. First, battery capacity will need an upgrade to support the higher power consumption. If more batteries are added to the system it is likely that more Battery Charge/Discharge Units will be necessary to support those batteries. Additionally, a new Sequential Shunt Unit may be necessary to ensure that the equipment is not being overloaded. With the exception of these few components the internal workings of the power system is the same and accounted for in the Dragon's 4700-kg mass [59].

On the off chance that the components within the Dragon are completely incapable of being used with a higher power production, a fully designed system is described in Appendix G.

Standard of Living

Life Support

The ECLIPSE Life Support subsection is responsible for researching and designing the hardware that will provide a comfortable and habitable environment for the ECLIPSE crew members on their 501 day trajectory. In designing the life support system, ECLIPSE focused on providing a reliable, comfortable, safe, and complete system consisting of previously developed components when possible. Life support systems' primary functions include:

- Monitoring and maintaining cabin pressure, temperature, and humidity; known as Atmosphere Revitalization System (ARS).
- Providing a closed loop system for the revitalization of oxygen and water (potable and hygienic), while removing toxic gases, especially carbon dioxide; termed Closed-loop Life Support System (CLSS).
- Water filtering and recirculation
- Waste management and repurposing
- Fire and Hazard Detection and Suppression

This complete life support system will be the closest to a closed-loop life support system ever flown on a manned mission. Development and implementation of such a system would be indispensable for the future of long-duration manned spaceflight. Life support systems are indispensable for human exploration of deep space. On Earth, all the elements needed for life are provided for, passively, by nature; water, atmosphere, waste management and ultimately, recirculation of these materials occurs naturally. From this model it is obvious that direct supply of consumables for the extended support of life is impractical. For this reason, a fully closed loop model of a life support system need be developed if humanity hopes to explore past LEO. A closed loop system would recirculate the consumables on board with very little excess consumable storage. Current ISS technologies are not closed loop, and are also extremely heavy. The ECLIPSE team developed a theoretical yet highly practical system which could be ready for a 2018 launch.

ECLIPSE's life support vision is to redesign life support systems to achieve lower mass, high efficiency, more closed loop, high levels of maintainability, and ultra-reliability. Due to mission time constraints, most emphasis is placed on technologies and systems which ECLIPSE considers to be, currently, the most limiting factors for long duration missions. Additionally, the technologies presented are viable for the 2018 launch, but some suggestions are made for technologies for a later launch. The design choices made for the 2018 launch are detailed in the following sections. While many technologies can be borrowed from the ISS, these are used conditionally, assuming the mechanical reliability of all the systems can be improved.

In order to minimize the amount of supplies carried on board, it is necessary to recycle all vital compounds (food, water, oxygen, etc.) In a closed loop system, vital compounds (H_2O, O_2, etc.) will be supplied by subjecting discarded compounds (CO_2, food waste, urine, etc.) to chemical processes which convert them back into the usable, vital compounds. It may not be possible to have a 100% efficient loop, e.g., an excess of H_2 or O_2 needs be stored to maintain equilibrium throughout the duration of the mission. Nevertheless, there exist processes with significant research that may be viable options to attain the highest closed loop efficiency.

Research of the life support system processes was conducted with the intention of seeking systems which would conform to the ECLIPSE's life support vision. This meant researching existing life support systems as well as the potential improvements that could be made before attempting to use or create more theoretical components. Figure 12 shows the most critical and novel components to CLSS designed specifically for the ECLIPSE mission.

A more in-depth analysis of all life support systems and a stoichiometric balance is provided in Appendix H. The balance in the appendix utilizes values from Hanford (2006) individually multiplied by some factor to account for the difference in crew sizes, mission duration, and improvements in technology [60]. All of the components in the flow chart and table have been researched, and show promise that with minor improvements in reliability and mission specific sizing, can be used on this mission. This report outlines the systems chosen as baseline components for future improvement and development, except in the case where the technology will be nearly identical to that on the ISS.

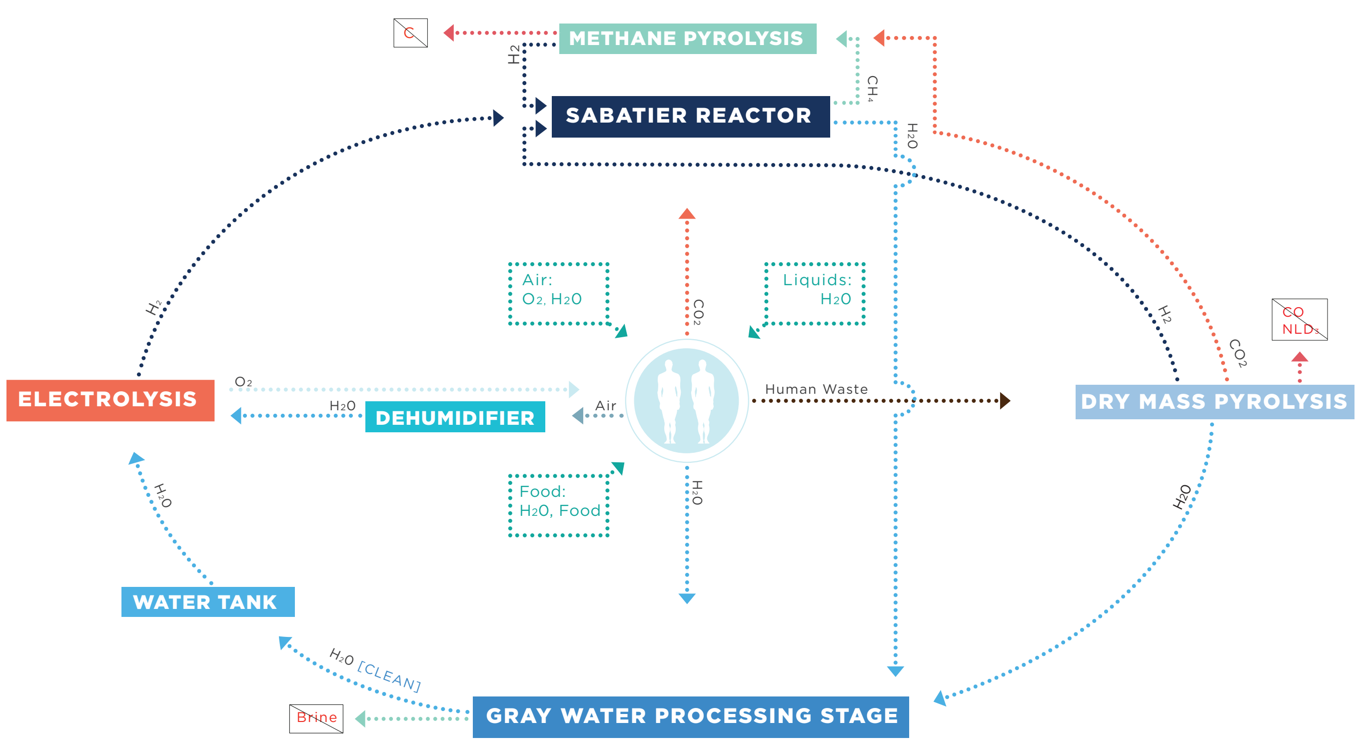


FIGURE 12: The ECLIPSE CLSS flow chart: Details the processes of the closed loop system and primary products produced by each.

Atmosphere Revitalization System (ARS)

The purpose of the ARS is to monitor and maintain the pressure, humidity, temperature, and gas levels in the cabin. The pressure technologies existent on the ISS are sufficient for this mission.

Thermal control on the shuttle can be broken down into two categories: avionics cooling and ambient temperature control. The Dragon capsule will have preinstalled avionics heat exchangers to provide cooling, and the ambient temperature controls currently on the ISS prove sufficient for this mission.

The carbon dioxide removal assembly is the most critical part of the ARS due to CO_2's consistent production through respiration. A state of the art technology is being developed by Hamilton Sundstrand for the Orion shuttle, called the regenerative pressure-swing assembly with an amine-based sorbent, SA9T [61]. The significance of this technology is its small size compared to traditional systems and its ability to be used for multiple purposes: CO_2 removal, humidity control, and a low temperature cooling loop. Additionally, not only is CO_2 removal an issue, but the removal of other trace gases is as well. A new trace gas contaminant control is being developed for the ISS by the European Space Agency. The Analyzing Interferometer for Ambient Air (ANITA) will be the next generation of cabin atmosphere monitoring. These systems remove CO_2 and trace gases from the cabin air, preparing them for processing. Between the SA9T and ANITA, the ECLIPSE Mars mission will possess a low mass, state of the art ARS system.

Air Processing

In order to maintain the necessary partial pressure of oxygen of 760-mmHg in the cabin, the oxygen consumed by the crew must be constantly replenished. Water, H2O, can be split into hydrogen and oxygen molecules by electric current, this is known as electrolysis; the chemical formulation is:

$$2H_2O \rightarrow 2H_2 + O_2 \qquad \Delta H = -286\frac{kJ}{mol}$$

It is anticipated that a crew of two will require upwards of 0.73-kg/day of O_2. Electrolysis involves placing an anode and cathode in a volume of water with sufficient voltage difference to activate this process. In ECLIPSE's life support model electrolysis proves to be the most efficient method of replenishing oxygen while simultaneously providing the hydrogen necessary for the Sabatier reaction (described later). Currently, the ISS uses electrolysis in its life support cycle; however, those systems have proven inadequate for long duration flight missions due to power inefficiencies, unreliability, and size requirements. Paragon Space Development Corporation (PSDC) is currently developing a Solid Oxide Electrolysis system in tandem with a Sabatier reactor subsystem which will enable 100% oxygen regeneration. PSDC's next generation system acts completely passively and is expected to be fully functional in a microgravity environment [62].

Historically, space systems vent carbon dioxide; however this loss in the system means frequent resupply missions are necessary to maintain the in-cabin environment. The Sabatier reactor decomposes carbon dioxide extracted from the in-cabin atmosphere and recombines it with hydrogen from electrolysis to form water and methane by the following chemical process:

$$CH_4 \rightarrow C(s) + 2H_2 \qquad \Delta H = -75.6\frac{kJ}{mol}$$

This is a crucial step in closing the life support loop. The first test of a CLSS that does not vent carbon dioxide and utilizes the Sabatier reaction was performed in 2013 aboard the ISS and is showing promising results. Furthermore, Precision Combustion Inc. has recently developed a Sabatier reactor using state of the art technology known as Microlith Catalytic Technology [63]. The ultra-fine filtering mesh used in this system proves to be highly efficient, light weight, and most importantly, low maintenance. Previous testing has shown that a reactor of approximately 12-mL provides enough capacity to provide for a crew of six. Furthermore, current prototypes of this reactor have

undergone extensive vibrational and durability testing with little performance degradation. The ECLIPSE mission will incorporate this technology by 2018.

The primary products from the Sabatier process are water (H_2O) and methane (CH_4). While the water can be recirculated through the water processing units, the methane must undergo a separate chemical process before being reusable. Through methane pyrolysis and hydrogen membrane separation, 0.73-kg/day of methane can be decomposed into solid state carbon (C) and hydrogen (H_2) as shown below.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \, \Delta H = -165 \frac{kJ}{mol}$$

The resultant hydrogen can then be cycled through the Sabatier process. Currently, there are no practical uses for the resultant solid carbon, and this will likely be the case for the 2018 launch. However, some theories suggest using the solid carbon as activated charcoal for use in filters, whilst more advanced theories suggest using it as material for 3D printing using nano-carbon tubes.

The use of methane pyrolysis for life support systems is still under research by many institutions. This reaction's high enthalpy requirement makes it a difficult process to achieve in a small system. The Jet Propulsion Laboratory in Pasadena has produced several articles on the topic, but no concrete technology has yet to be developed. More research and mission specific development is needed before this technology can be utilized [64]. Kenn writes about a simple method using heated ceramic foam to heat the methane to decomposition [88]. By alternating a heating reactor with a cooling/cleaning reactor to eliminate solid carbon this method seems plausible. Although not yet technologically developed, methane pyrolysis has drawn the attention of many researchers as a possible step in long duration life support systems and is being heavily researched. If practical systems are developed by 2018, the ECLIPSE mission will integrate methane pyrolysis. In the case that methane pyrolysis is undeveloped, approximately 800-kg of excess hydrogen must be stored to compensate for the wasted methane. The Sabatier reactor must have sufficient products to operate for the 501 day duration.

Water Storage, Processing, and Recirculation

In a long duration mission the lack of resupply missions means that all water aboard the vehicle must be recycled and reused with as high a fidelity as possible. ECLIPSE has chosen several technologies that serve to capture, sterilize, and recirculate nearly 100% of the water aboard the capsule. While the majority of the systems aboard the ISS are close to suitable for the Mars flyby mission, two new technologies are introduced here; Vapor phase catalytic ammonia removal (VPCAR) and lypholization. Wastewater generated from cleaning and sterilization of the spacecraft and urine will be termed grey water.

The water recycle system currently aboard the ISS utilizes expendable filters and adsorption beds to purify its waste water streams. This creates excess waste and crew time necessary for servicing these components. VPCAR is a process which evaporates wastewater such that only vapor and volatile (organics and ammonia) components remain. This is then oxidized in a catalytic reactor to remove contaminants. The final product is a condensed, purified water stream. VPCAR not only requires no expendable except oxygen, but also possesses higher water recovery rates of up to 98%. Recently, the technology has reached a new level of technological readiness and future plans include testing aboard the ISS. All grey water streams would be processed through this system on the 2018 mission [65].

Lypholization, also known as cryodessication, involves freezing materials and then exposing them to a low vacuum to vaporize the ice crystals formed. By running any wet effluent streams through this process water recovery is significantly increased. A freeze dryer would fill the gap between the wastewater and the Waste Management System by removing all water from the mixture. Testing of a prototype by Stanford in conjunction with NASA Ames determined that lypholization yielded up to 98% water recovery, leaving only 5% water by weight in the dried product. The utility and relatively low mission cost in applying this technology makes it a perfect candidate for the 2018 mission.

Based on mass balances found in the Appendix H, ECLIPSE has determined that 460-kg of water would need to be stored on the capsule prior to launch. An important suggestion for the storage of water and the general infrastructure of water circulation on the capsule is that, as much as possible, water should be stored along the walls and in sleeping bags (see Radiation Shielding Final Design). This keeps the added mass of water from being parasitic to the mission, and instead doubles as an additional layer of radiation shielding.

Waste Management System

One of the most complex problems facing an advanced life support system is the recycling of solid mass waste. This section of life support is concerned with conditioning solid waste including packaging, human wastes, inedible biomass, and potentially brine collected from the Water Subsystems. In shorter duration missions, solid waste is typically stored until the transit vehicle returns to Earth. The Eclipse mission will condition, recycle, and in some cases repurpose these solid wastes. It is important to note that the waste management system will only be able to recirculate biowastes. This means that, in order to simplify the constituent chemicals of the solid waste, food and materials packaging should be made of biodegradable materials, if possible. This would reduce the products of all solid waste treatment methods to some combination of C, H, O, and N. Furthermore, pretreatment of all waste would include lyophilization (see section 5.3.7) to remove water prior to processing.

The solid waste processing system is termed Dry Mass Pyrolysis. This technology would involve thermally decomposing the solid waste in an oxygen-free environment. 0.22-kg/day of produced intermediate gases and char can be extracted and then further processed, e.g., processing carbon monoxide (CO). The primary disadvantage to this method is the fact that until now, there has been little to no research on feasible space shuttle technology. However, a third generation prototype pyrolyzer has been developed by Hamilton Sundstrand Space Systems and has demonstrated effective proof of concept [66]. Additionally, Ames Research Center has developed a waste incineration system capable of meeting adequate spacecraft contaminant levels, but has seen no commercial application [67]. Regardless, ECLIPSE is confident that with sufficient funding these technologies could be developed to see use in a 2018 mission [68].

An additional solid waste processing system would be the heat melt compactor currently being developed by NASA Ames. Any non-biological wastes generated by the crew such as plastics and metal from equipment repairs can be ran through this process. Heat melt compaction utilizes a high heat-high pressure to reduce the volume of wastes to a compacted solid waste puck. If these pucks could be stored along the spacecraft walls, the waste would double as radiation shielding; the efficiency of which is amplified by the fact that the pucks are made of a high percentage of hydrogen [69].

Innovative Technologies

The problem with traditional life support systems is the mechanical systems themselves. They are prone to failure, complex, and require large power sources to function properly. Any improvements tend to make them more complex and consequently require more servicing by the crew. An ideal closed loop life support system would work almost completely passively, be highly redundant, and require little power. Water Walls Architecture presents an elegant solution to these issues.

Water Walls will provide the functions of thermal and humidity control, CO_2 removal, O_2 generation, grey water processing, and biological solid waste processing [70]. Removing all mechanical systems associated with these processes would greatly reduce the mass, volume, and power consumption of the life support systems. The Water Walls design consists of a series of polyethylene bags which pass various waste streams to each other and the environment through forward osmosis in order to carry out the necessary functions for life. Each bag is designed for a specific function and are organized in correspondence to these functions. Each bag fills overtime with organic wastes,

and when full, will automatically cease operation and simply serve as a radiation shield. Current ground tests place the water recovery of the Water Walls system at over 99%. Figure 13 shows a computer model of how these bags can be tiled around the walls of the transit vehicle. Experimental models using Bigelow's Inflatable BA 330 module have been created by Astrostructure in Pasadena, CA. These bags were designed with the idea that they would simulate the passive nature of life support on Earth, including additional radiation shielding by adding layers to the capsule walls. Currently, the technology is scheduled for an integrated system test aboard the Bigelow Inflatable Module. If this test is successful, water walls would be the conclusive solution for advanced life support systems, and would need to be adapted to ECLIPSE's capsule-module assembly for the 2018 flight.

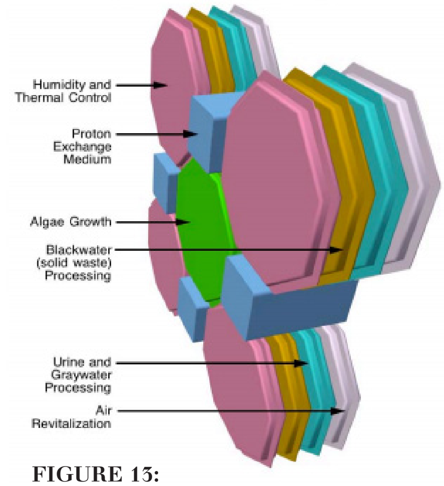


FIGURE 13:
Basic water walls architecture

Physical Health

The continued physical health and safety of the crew is a mission priority. Therefore, a large focus was placed on ensuring complete medical coverage for the crew over the 501-day mission, as well as laying the foundation for scientific experiments. To reduce costs and ensure on-time development of mission equipment, the team primarily selected flight-ready equipment tested on ISS. Complete medical care was ensured by placing a focus on non-invasive, re-usable medical diagnostic equipment for the purpose of monitoring crew health. These medical devices are recommended for inclusion to also improve the experimental capabilities of the mission, enabling biomedical research protocols to be conducted on crew members. Additional experimental platforms were included in the simple and versatile rack system later described, laying a broad experimental infrastructure in the fields of plant science and biology. ECLIPSE also recommends providing ample space for additional experimental equipment to be proposed in the coming years by researchers. This will ensure the broadest scientific impact of the mission and could, in part, offer financial support for the mission.

This unprecedented mission length brings the maintained health of the crew into question. Physiological responses of the human body to exposure to high levels of radiation and microgravity cause systemic health issues that can compromise the success of the mission. Effective countermeasures are necessary to maintain the health of the crew throughout the mission duration. Overall, a robust physical health system is required to ensure that the crew returns to Earth in full health.

Preventative Health

Neural System

The high-risk nature of this mission raises the chances of having to perform surgery during the mission to preserve the life of the crew members. Non-essential medical procedures will be postponed until return to LEO or Earth. There have been limited examples of the use of anesthesia on animals in microgravity and no recorded incidences of human testing. A high incidence of surgical complications exists, sometimes leading to death of the subject. However, operating without anesthesia is not recommended [71]. The highly complex nature of anesthesia efficacy makes for a difficult area of study. More research is recommended to monitor the controlled microgravity anesthetic studies and wide use of analgesics, when possible, is recommended.

Physiological alterations in microgravity have implications on the changing absorption, distribution, metabolism

and excretion of pharmaceutical medications. It was determined that in most cases, microgravity physiological changes could cause a decrease in the potency of the drug. This, despite being un-ideal, is safer than the alternative case of an accidental overdose. Potentially dangerous situations arise when the drug's metabolic enzymes become inactive due to space flight, causing the drug's half-life to increase drastically. Certain drugs have been tested in microgravity, including sleep aids (Ambien/Sonata) and nausea suppressors (Promethazine). It is also theorized that microgravity exposure could increase the resistance of bacteria strains, increasing the amount of antibiotics needed. The 501 day mission duration exceeds the standard antibiotic expiration date of 365 days, potentially reducing late-mission potency. In addition, radiation exposure is theorized to degrade the active agents in the pharmaceuticals. While the pharmaceutical storage space will see the same 0.981-mSv/day as the crew (see Radiation Shielding Standards), natural degradation of the drug will be still be accelerated. The combination of these potency reducing factors necessitates a large reserve of antibiotics. [72]

Vestibular System

Without gravity, the loss of a weight vector on the inner ear in the vestibular system is theorized to be responsible for the moderate space sickness experienced by crew members within the first few days of space travel. The current countermeasure procedure is to allow the ill crew members a few days to equilibrate. The crew will be spending 27 days in LEO while waiting for the arrival of the TMI engine, allowing a comfortable and supervised transition to microgravity.

Digestive System and Nutritional Requirements

Despite ample fresh and natural foods available on ISS and a robust nutritional regime, crew members have a markedly decreased caloric intake. It is theorized that physiological changes in the mechanics and chemical actions of digestion, as well as increased nasal and sinus congestion, decrease the appetite of the crew members. As described in detail in the Mental Health section, a variety of food types, colors, odors and textures is important for crew members to keep a healthy appetite. Strong odors are also discouraged in the closed space due to limited ventilation. Adding water to food both acts to keep the food together, minimizing debris, and broadens textures of the food. Altering the temperature of the food, using heated International Subsurface Interface Standard((ISIS) drawers and refrigeration units, also improves the crew members' perceptions of the food.

	Men	Women
Protein (g)	133	97.5
Carbs (g)	484	358
Fats (g)	137	101
Daily Subtotal Food (g)	754	557
Total Food (kg)	377	279
Daily Water (kg)	3.00	3.00
Total Water (kg)	1500	1500

TABLE 14: Metabolic requirements and food masses required by crew members on long-duration space flight.

Space food comes in several forms. Frozen foods will not be widely used in the mission, due to the high climate control requirement. Likely, thermostabilized foods, like canned goods, will also be avoided due to the fact that they are very heavy. Fresh foods and refrigerated food items are highly beneficial for their nutritional value and mental health benefits, but the short shelf life implies their applications will be primarily in the early portion of the mission. Immediate moisture foods, rehydratable foods, natural form foods, and irradiated foods will he heavily relied upon. Immediate moisture foods, like dried fruits and meats, and natural form foods, like nuts and granola bars, are ideal because they require no preparation and they have a high nutritional value for their weight. Rehydratable foods, where water is removed for easier storage, will be used because of the variety of foods able to be preserved in this manner. Similarly, irradiated

foods, which are cooked and sterilized with ionizing radiation to enable storage at ambient temperature, are ideal because they mimic natural foods with longer shelf lives. Therefore, when available a robust and diverse diet consisting of food with long shelf lives and minimal preparation to encourage crew member nutritional health. [73]

The nutritional requirements of the crew were determined from the recommended nutritional intake of crew members as reported by NASA's Nutrition Team. An additional 500-kcal/day are required on days of any heavy physical activities, such as mission countermeasures. A breakdown of daily and total food and water required is included in Table 14. Military grade ready-to-eat meals were used to determine the volume of food, as included in the mass and volume breakdown in Appendix C [74]. Detailed nutrition calculations are included in Appendix I.

Musculoskeletal System

The musculoskeletal system atrophies a great deal in microgravity, leading to many physical ailments that could affect mission success. On a 500 day mission without proper countermeasures, bone density will decrease 15% in the lumbar vertebrae and 20% in the femur [75]. Musculature decreases far more rapidly in the muscles required for stabilization under gravity, seeing a localized loss of upwards of 35% in just 20 days [76]. Landing vehicle dynamics is the most likely loading event that will injure the crew members. A possible bone fracture or a herniated nucleus pulposus/annulus fibrosis tear is likely due to the increase in forces and the dynamic vehicle vibrations during landing [77]. As mentioned previously, the limits on reentry decelerations are recommended to be at maximum 8-g's and 6-g's to ensure crew safety (see Reentry). Countermeasures must be developed to ensure minimal musculoskeletal degeneration to prevent serious injury occurrence during landing.

It was determined that a combination of aerobic and resistive exercises will be ideal for maintenance of musculoskeletal and cardiovascular health [77]. Currently used aerobic devices on ISS include stationary bicycles and treadmills. The aerobic exercise device for this mission is preferred to be a treadmill, to increase the mechanical loading of the lower limb in an attempt to slow bone loss. To increase simplicity in mission development and reduce overall cost, the use of the Combined Operational Load Bearing External Resistance Treadmill (COLBERT), currently in use on ISS, is recommended. Not only is the COLBERT a space-flown technology, but the system was designed to be highly reliable and can function with or without power, including its passive vibration isolation system [78]. However, the system's 1000-kg mass is not ideal. Therefore, it is recommended that further research is conducted to reduce the weight of the supporting rack. Statements made by Wyle Technologies, developers of the COLBERT, indicate that the development timeline limited their optimization of the design [79]. It is reasonable, then, that the COLBERT could be optimized with respect to mass over the development timeline of the Inspiration Mars mission. To expand on the experimental capabilities of the treadmill, a strain gauge is recommended for inclusion in the harness, measuring the changing tensile force in the harness to better calculate exercise loads. Additionally, a ground-reaction force plate under the tread belt to quantify workout intensity would further expand the scientific merit of the mission. If it becomes clear that the recommended improvements to the COLBERT are not realistic in the development timeline, a completely passive treadmill is recommended. A simplistic design, consisting of a polytetrafluoroethylene plane, low-friction crew footwear, and an exercise harness, can accomplish the exercise goals of the crew members in a passive, highly reliable, and cost-effective manner. However, a treadmill, capable of recording running speed, would be preferred.

Resistive exercise has been shown to maintain a healthy bone mineral density and overall skeletal strength [80]. The resistive exercise device is recommended to be the Advanced Resistive Exercise Device (ARED), currently in use on the ISS. The ARED has mostly curbed bone loss and is capable of maintaining most muscle mass during long-term (~6 month) missions. A study by Smith et al. in 2012 demonstrated that the ARED maintained total bone mineral density (BMD) over the course of a long-duration spaceflight better than the interim Resistive Exercise Device. For flight durations of 4.9±2.05 months, the percent change in pelvic BMD was shown to be -1±1% with the use of ARED, com-

pared to the -8±5% change demonstrated by use of iRED [80]. The ARED is the most effective exercise system available and is absolutely necessary for this novel 18 month mission. The ARED is a large piece of equipment, however, taking up 7% of the habitable volume of the MPLM [72]. Design alterations to ARED, decreasing the size and mass of the equipment without limiting the capabilities of the machine, would greatly improve quality of the mission [77].

Renal System

A fluid shift occurs from the loss of gravitational loading, causing blood that normally pools in the lower limbs shifts to become more evenly distributed throughout the body. The change in blood flow causes an increased flow to organs throughout the body, causing other issues. Increased flow to the kidneys caused the kidneys to become overexcited and they excrete more urine than physiologically necessary.

An ultrasound capable of Extracorporeal Shockwave Lithotripsy (ESWL) would be ideal. One mission-critical side effect of the altered cardiovascular system includes, due to the hyper-activity of the kidneys and dehydration, kidney stones. To mitigate this, several research groups are designing microgravity-favorable methods of dislodging kidney stones using ultrasound probes through ESWL. ESWL was developed in 1980 for the application of degrading kidney stones using focused ultrasound waves. An ESWL-capable ultrasound is much higher powered than a conventional ultrasound machine, implying the necessity of a second machine. However, current ESWL procedures do not translate well to space travel. The high powered waves create a risk of renal damage from the ultrasound vibrations, which could be damaging if the kidneys of the subject are in poor shape. In addition, the procedure is usually conducted under anesthesia. The use of anesthesia in microgravity has, to date, not been tested and is elaborated upon below. Due to the high level of accuracy necessary for this procedure, patient stabilization will be necessary to minimize organ damage [81]. However, a microgravity-capable system under development by Simon et al. at the University of Washington shows promise by greatly reducing the risk of renal damage through a user-friendly interface that requires little training [82]. The rapid product development and robust testing schedule demonstrated by Smith et al. encourages the inclusion of this device.

Telemedicine

Due to the unprecedented mission duration, the risk of a crew member having a mission-compromising medical ailment requiring treatment increases drastically. On ISS, crew members are trained in Telemedical techniques and are capable of being walked through complex medical procedures by a ground-based surgeon. However, significant communications delay implies that Telemedicine will likely not be fast enough. Therefore, it is advised that crew members be adequately trained in medical techniques, allowing for effective medical treatment during transit. Due to the limited crew size, both crew members should have similar medical training and, when possible, be trained to self-administer first aid. For complex medical procedures, written and illustrated instructions are recommended to be available on board for reference. The crew members will be familiar with the instruction manual to ease operations in high-stress operations. In addition, a comprehensive list of medical diagnostic hardware will be included on board to facilitate diagnosis of crew members. In low- and medium-risk situations, medical data will be transmitted to the ground-control surgeon for consultation prior to medical intervention. Medical supplies will be available for crew use as needed, stored in the human research facilities (HRF) racks.

Medical Diagnostics

With limited medical capabilities it is important that the crew have access to easy-to-use medical monitoring and diagnostic equipment to identify possible health issues before they become mission critical, reducing reliance on

emergency medical procedures. Medical monitoring on ISS is conducted through the use of several biomedical devices on a larger multi-purpose rack. The Health Research Facility 1 and 2, currently in use on ISS, house important medical monitoring equipment in modular spaces, facilitating the diversity of the racks. For the purposes of this mission, only some of the modular spaces in the two racks flown will be designated for medical diagnostic equipment. The remaining space will be open for scientific equipment. An advantage to maintaining the rack-system for supporting medical diagnostic equipment is that equipment development will be greatly reduced and, in some cases, already completed. The equipment selected to be housed in the HRF racks are included in Figure 14. This equipment was critically selected from equipment tested on ISS missions to allow the greatest breadth of medical diagnostic and experimental capabilities. Further rationalization concerning the selection of diagnostic equipment is included in the appendix (see Appendix J).

Medical imaging diagnostic on ISS is currently heavily limited by the type of machinery that is long-duration spaceflight-compatible. A magnetic resonance imaging (MRI) is much more versatile than an ultrasound machine, imaging all biological tissues. A compact MRI machine is currently under development by a team at the University of Saskatchewan headed by Gordon Sarty. The machine takes up only 1-m^3 of space and is capable of diagnostic-quality MRIs. The current prototype machine weighs approximately 1,000-kg and the final prototype will theoretically weigh 500-kg. Inclusion of the technology in the mission will greatly increase the quality and capability of remote medical imaging. It is recommended that the development of this MRI is monitored for possible inclusion. [83]

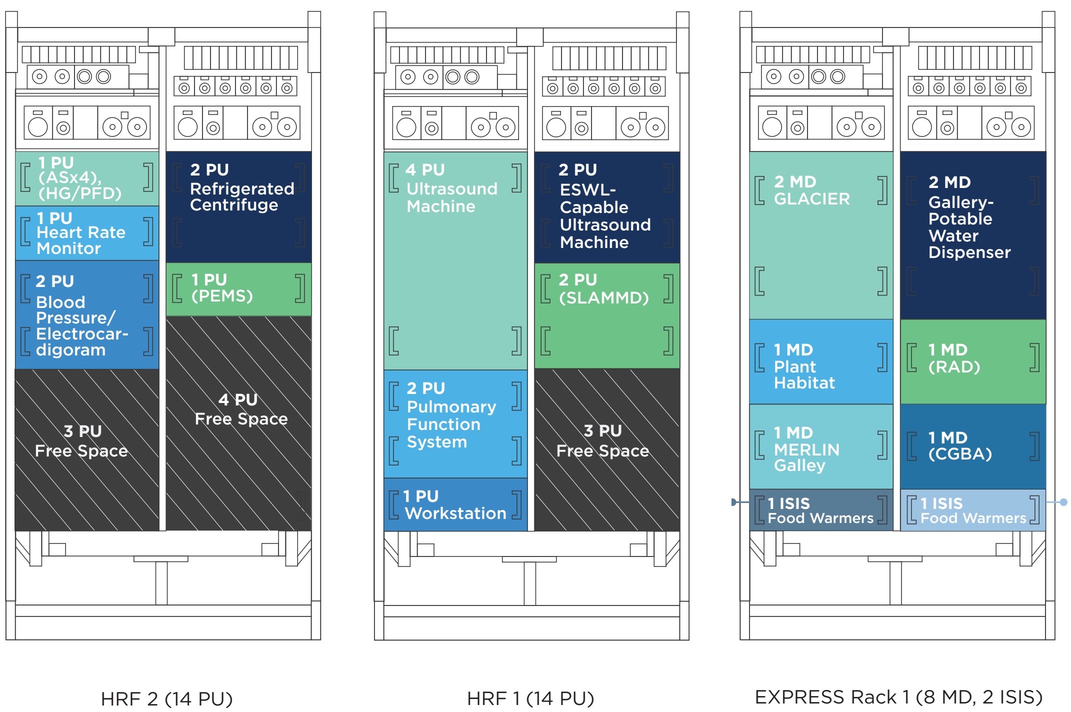


FIGURE 14: Physical orientation of medical equipment.

PU = Panel Units
MD = Middeck Drawer

Surgical Enclosure

Performing remote surgery in microgravity is largely unknown and one issue is blood pooling around abrasions and incisions, occluding the surgical area. In addition, any blood that is improperly removed from the surgical area could harm sensitive equipment and spread viruses and bacteria among crew members. A surgical enclosure is under development by Hayden et. al that has the promise of mitigating these issues. With a flight test scheduled, it is very likely that this equipment will be ready for a 2018 launch date and, therefore, it is recommended for inclusion. [84]

Medical Sterilization

With flight durations increasing, it is becoming less feasible to carry disposable medical tools. Therefore, regular disinfection of medical equipment is needed if it is used more than once to reduce the risk of infection and spread of illnesses. This will necessitate disinfection/sterilization to remove the contaminants and to safely reuse medical equipment.

Sterilization of medical equipment dramatically decreases the rate of pathogen transmission [85]. The only flight tested sterilization technique is the use of Orthophthalaldehyde (OPA), currently used in ISS operations. It can be used as a high-level disinfectant for cleaning endoscopes, and can also prevent the buildup of biofilms in cooling loops [86]. It is highly compatible with equipment, has low risks for inhalation injury, and can effectively reduce bacterial loads. By integrating the use of OPA sterilization into the mission, waste can be reduced greatly and groundwork can be laid for the facilitation of longer mission durations.

Experimental Equipment

ECLIPSE seeks to host various on-board experiments in order to obtain sufficient funding and to gather vital information for future Mars missions. It is expected that these experiments will raise funds for the mission, increase the value of the mission to the scientific community, and expand public interest in the goals of long duration space flight.

Experimental equipment were selection with the goal of monitoring the effects of long term spaceflight on human health, to contribute to self-sufficiency and survival in space and Mars environments, and to further understanding of basic science in space environments. Therefore, the ECLIPSE team has selected a wide variety of experimental equipment, optimizing cost, operational simplicity, and the experimental capability. Hardware was selected for its versatility, compatibility, and ease of integration. A summary of the storage locations of the hardware is located in Figure 16 and rationalization is expanded upon in the Appendix (see Appendix J). With the suggested equipment inclusions, an experimental platform enabling the conduction, storage, and return of biological, chemical and physical research experiments.

Sleeping/Waking

Crew members need about the same hours of sleep on Earth as in space. According to NASA crew members are recommended to have 8 hours of sleep but researchers have also confirmed that crew members sleep about 0.5-2.5 less hours than recommended. The main worry during this mission is that the crew member's circadian rhythm will be disrupted during because of the constant sunlight facing their spacecraft. For this reason, specific lighting will need to be placed in the spacecraft to simulate night and day and keep them on a 24-hour circadian cycle (see Mental Health Section). Crew members will mirror the same day period as in space. However, this schedule can be altered if the two individuals would like by an hour in order for irritation not to increase between both of them (see Mental Health Section).

Grooming

Showering is complicated in space. In order to maximize efficiency and minimize waste, all water used must be recycled into the water system. Crew members will have the choice of taking showers with a washcloth and or from a plastic cylinder shower. This is a plastic cylinder shower that is three feet all around. This is a small area in the spacecraft that runs from wall to wall so water does not leak. Later, crew members use a nozzle to suck up all the water. Showering will occur 2 times a week during anytime of the crew members' grooming period which is similar on the International Space Station. Items that will be utilized for showering are rinseless shampoo, soap, and conditioner. Crew members will also brush their teeth after every meal because tooth decay in space is very high. They will use swallowable toothpaste and water from a small water bag that is usually used for drinking liquids.

Physical Health Final Design

The physical health and safety of the crew members is a top mission priority. Proposed alterations to the mission to prevent health issues and treat any medical ailments that arise are necessary to ensure overall mission success. In addition, the intellectual merit of the mission is greatly improved through adequate foundations for basic science research. Therefore, the ECLIPSE team is confident that the proposed mission alterations will not only greatly improve quality of life of the crew, but also increase the impact of the mission on scientific merit and social influence.

Mental Health

The crew health is not limited to just physical health. Isolation, monotony, and hostile living environments introduce the crew to psychological strains that can negatively affect mission success and crew health. ECLIPSE, therefore, examined methods to ease hostile psychological stressors, improving the mental acuity of the crew. A dynamic communications, lighting system, and noise reduction program is recommended for inclusion to ease the psychological stressors of isolation in a high stress environment. In addition, ECLIPSE recommends additional crew training and rehabilitation for this mission to ensure overall mission success. With these recommended mission alterations, ECLIPSE is confident that overall mission stress will be minimized.

There is a serious component of mental strain that will be placed on the crew members. Biologically, the space environment is the most hostile that humans have encountered. In addition, the close quarters, isolation, unchanging environment and long mission duration could have any number of effects on the mental stability of the crew members. ECLIPSE strove to account for the most serious of these, identifying and reducing the catalysts as well as proposing solutions once problems arise.

The current crew member selection process filters candidates by testing for serious mental disorders [96]. Most of these tests look for anxiety problems that manifest in erratic behavior, ranging from destructive impulses to hyperactivity, but leaving predispositions for depressive behavior largely untested [97]. Crew members and cosmonauts in the Skylab missions and stationed aboard the ISS have reported a disinterest in day-to-day life akin to hibernation by the later stages of a mission [98]. Such lethargy stems from the crew members' sudden physical and emotional isolation from human society and is worsened by the narrow confines of the space craft and a lack of environmental stimulation—isolation similar to that experienced by overwinter crews in Antarctica [99]. They are removed from society abruptly and receive limited information from home. Studies of crew members from previous space missions have noted a withdrawal from the rest of the crew and an increased desire for information from home as the mission progressed [100] Space crews have few distractions from their high stress situations and cope by retreating from common social constructs, negatively affecting their work and crew morale. ECLIPSE has identified five major issues that can be easily remedied at low cost while significantly improving overall crew health. These can include relieving feelings of isolation with communciation back home, overcoming disorientation with interior arrangement, and alleviating sensory depravation with lighting, color and noise control.

Communication

ECLIPSE's mental health team recommends that the crew receive weekly non-mission critical information from Earth. Every Friday, personal e-mails from family and friends and brief but variegated news stories, should be exchanged. Sending the information at the end of the workweek helps maintain the social norm of working toward a reward for a week of work. Every other week, pictures should be sent on Saturday, both to break up the volume of information sent over two days and to give an added variety of information. Every four weeks, and on special occasions,

five minute videos from family should also be sent. The videos are the most intimate information sent to the crew; offering the most similar substitute for human interaction that technology can easily offer without physical contact, maintaining a feeling of belonging and normality, and staving off depression.

Interior Arrangement

The interior interfaces and equipment of the spacecraft will become the crew member's home for 501 days. Like any home, the organization and effectiveness of all interfaces can greatly affect the crew members' moods and mental state. ECLIPSE strove to anticipate and remedy issues due to the space limitations of the spacecraft, including arrangement of living space and lighting systems.

On Earth, gravity offers a directional orientation, constrainig objects of interaction to the plane of gravity. Optimizing the use of the available space can be disorienting for those used to a fixed coordinate system. Crew members on the ISS have reported stress caused by this disorientation, and even more so by the seemingly infinite expanse of bulk packages around them [98]. ECLIPSE suggests the interior be arranged to counteract this effect, maintaining a consistent direction of interface whenever possible. This means allowing for spaces to be devoted to exclusive tasks, such as food storage kept near the kitchen space for the crew to quickly and easily access meals without moving back and forth across the entire space craft. The crew members are free to modify the arrangement to accommodate personal preference, but are encouraged to interact with equipment in a reference frame reminiscent of a gravity dependent system.

Lighting and Color

Crew members and test subjects from the Mars 500 study have complained of a monotonous environment during flight, including lack of color and variety [98, 101]. Current color schemes aboard all of the ISS modules perform less than adequately in stimulating and maintaining crew members' interest. This problem will become prominent for this mission due to its long duration and limited living space.

The most promising solution is to have a dynamic lighting system for the entire living space. ECLIPSE intends to employ a net of small, efficient lights (such as micro light-emitting diodes (LEDs)) capable of a wide range of colors varying in shade, hue, intensity and brightness. Disney currently has a sophisticated light system for the World of Color attraction at California Adventure that utilizes a network of LED lights similar to ECLIPSE's needs. The individual light sources should be placed behind equipment, or low-level translucent screens to filter out the harshness of the light source and create a general glow in the desired space. The lighting should be designed and programmed to be adaptable and customizable. The option to modify the lighting will give the crew much needed control over their environment [98]. The lighting system will be programmed to change on a daily cycle, mimicking a circadian rhythm to cue crew members on a subconscious level of a sleeping and waking cycle, helping to overcome the current issue of insomnia reported by crew members during missions. In addition, each day will follow the seasons and imitate weather. For example, daylight will grow longer and shorter as Earthly seasons pass. The light quality will change noticeably enough to indicate change in seasons, e.g., lowering the intensity and increasing the red and yellow hues can resemble fall. Every day should vary in some very minor sense, be it resembling weather patterns, general color schemes, or modifying saturation to give the crew a sense of daily change. Even the most subtle lighting changes will offer novelty in an unchanging routine.

Noise Levels

Running machinery, such as life support systems or experimental equipment produces continuous noise from 30 to 190 Hz [98]. Studies show that crew members aboard the ISS unconsciously avoid certain areas of the space craft,

specifically ones that serve as a focal point for and emanate the lowest frequencies [102]. Where past crew members have complained of a feeling of discomfort when entering these areas. The livable space in the capsule for this mission is limited, making it absolutely necessary to resolve any noise issues that could further limit the crew's living space.

Headphones were discarded as an option, providing discomfort, and posing the risk of crew members not hearing each other or alarms during an emergency.

The alternative is to have noise cancelling devices installed either in or on the machinery. This technology is currently available from Silentium [102]. This device is preferable to headphones because it can eliminate targeted sound frequencies from the machine it is installed on. For example, a machine makes noise ranging from 30-Hz to 90-Hz and has the Silentium noise cancelling chip installed. The chip can be adjusted to recognize and minimize that range. Should the machinery break and start making unusual noise, the crew will be able to hear it and remedy the problem.

Crew Selection, Training, and Recovery

Training

It is nearly impossible to predict exactly what information the crew needs to learn. There are an infinite number of situations that could come up on a 501 day voyage, many of which require instant action from the crew. An emergency is unlikely, but still possible [104]. As the mission progresses and the capsule moves farther away, communication delays with ground control will lengthen, making the need for thorough training critical for crew safety.

ECLIPSE recommends specializations should be added to the training program. Rather than giving both crew members a general spread of everything, have each crew member get extra training in specific fields. For example, one crew member gets a very thorough course on the life support machinery/equipment while the other becomes an expert at debugging system software. After the mission has launched and the crew has set up the capsule, they can spend some amount of time orienting the other crew member as to the nuances of their specializations. This will help the dynamic of the crew by giving each exclusive strengths, allowing each to have some command depending on the situation. The drawbacks include the possibility of the crew member with a certain specialty being incapacitated when that skill is required. However, the likelihood of the crew member being incapacitated during a serious emergency involving the capsule functions is low. In this scenario, the remaining crew member would be dependent on ground-based experts for instruction.

Post-Mission Recovery

The current method of recovery for returning crew members from the ISS is not thorough enough for our mission. The crew will spend over three times as long as cosmonauts aboard the ISS in space and in more restricted living conditions. After returning from the ISS, crew members are paired with a medical doctor and a psychologist to review their physical and mental health. In addition, crews are kept away from the public eye. A 'gatekeeper' regulates who can visit the crew members—including family, friends, and media [105]. They will also be more physically and mentally unstable than crews from previous missions due to the length and totality of their isolation. As soon as the crew lands back on Earth, they will have social expectations placed on them that will require poise, cleverness and charm; traits difficult to achieve even in a healthy state as shown by the discomfort of the crew during the press release of the Mars 500 mission [106].

In addition, the crew will experience an emotional 'vacuum' after returning. ECLIPSE recommends certain

modifications to the standard procedure in order to protect the crew member's wellbeing, including more stringent guards against people contacting the crew (including the other crew member). To help the crew rehabilitate, they should train and work with a specific group of people. Currently, potential crew members in the selection process train and work together — sometimes groups up to fifteen times the size of the final crew [107]. The trainees not selected for the final crew continue to work in supporting roles alongside the chosen crew such as ground control and mission design. As a special modification for this mission, the trainees not selected for the mission will still include mission control specific training for the non-crew members, creating a more intimate relationship between the crew and mission control and help ground control to better relate to and communicate with the crew during the mission—providing more emotional support for the crew. This will also give the crew more familiar faces upon return to assist in the emotional recovery from the trip.

Cost Analysis

Creating an accurate cost estimate for a novel mission of this magnitude presents many challenges. First, the nature of technological development with mission planning means development problems can quickly change an items cost. Furthermore, advanced and high-cost components are often developed and built inside of large contracts. There are rarely explicit "sale prices" as are familiar in consumer markets, which can lead to varying levels of estimation in the following numbers.

ECLIPSE strove to create a low-cost mission design by applying a set of guiding principles to all technical choices:

1. Active usage- Items in active use were chosen over those needing further development. Next, items with a high technological readiness level (TRL) are preferred over those with lower TRLs. Manufacturing techniques and product designs of these items will be optimized for cost-efficiency by the time of Inspiration Mars's purchase.

2. Simplicity- Technologies that can be easily implemented are given precedence. Simple technologies that serve multiple functions, increase simplicity and reduce the number of systems required will be purchased.

3. Developer profile- The developer plays into the cost of the purchase, the design philosophy and manufacturing methods of the product. The manufacturer also determines the speed and expense of any custom modifications. The contrast between Government agency, large-scale commercial contractor and small-scale private cost structures is stark.

Trajectory

The free return trajectory was chosen because of the minimal time of flight and the low energy required. As a result this reduces overall costs throughout the mission.

Spacecraft

The Spacecraft cost is estimated at $269,000,000.00. This includes the cost of the MPLM and the SpaceX Dragon Capsule with all modifications. MPLM cost was based off the $300 million contract NASA paid to the Italian Space Agency for 3 modules. SpaceX lists cost per ISS flight at $140 million. This mission will have a considerably longer duration and more modifications because it will put more strain on the reusable heat shield, require a trunk exten-

sion and installation of the custom RS-72 based booster. These items impacted the total cost and were estimated and summed to arrive at the total Dragon cost. SpaceX development philosophy is efficient and cost-effective. The company leadership benefits from Silicon Valley ideals – lean manufacturing, vertical integration, flat management- all designed for cost-efficient operation

Launch

Launch system costs a total of approximately $247,000,000. The overall cost consists of three launch vehicles, (two FH, and one Falcon 9), along with two modified boosters to store the required propellant. SpaceX releases cost values for their launch vehicles, which confirms it provides cheaper options than its competitors (as discussed in the Launch Vehicle Section).

Radiation

The total overall radiation system cost is approximately $446,000.00, which includes the cost of materials and manufacturing of the aluminum and HDPE. These materials were determined to be the most effective for radiation protection while maintaining manufacturability.

Communication

The overall communication systems total cost was approximately $188,000,000.00, which includes the MRO Hardware, DSN, and Near Earth Network. DSN and Near Earth Network are the only systems currently available, which makes them readily effective and reliable choice.

The algorithm for computing DSN Aperture Fees is used to maximize DSN utilization efficiency. It evaluates weighted hours to determine the cost of DSN support. Refer to Appendix F for the details of this algorithm. The total cost estimate for DSN reservations using all stations at various times on an average of 0.5 hours/day is approximately $7,477,799.35.

The Near Earth Network will be utilized for launches, assembly, and reentry. This will incur cost by the rates contained in Appendix F, the total of which is estimated at $78,600.

Cost estimate for the MRO hardware from JPL is estimated to be about 25% of the overall cost the mission (Prime Contract 1234906 between Lockheed Corporation and Jet Propulsion Laboratory). This estimate would be about $180 million total for the MRO.

Power System

The total power system costs approximately $3,900,000.00. Spectrolab has set the record for the most efficient solar cells produced, which helps save in costs. From this, ECLIPSE suggests ordering solar panels from Spectrolab, which charge $250 per Watt. The solar panels designed for ECLIPSE will produce 8kW at Mars, which corresponds to 15.6kW at Earth, making the total price for the solar panels $3.9 million.

Life Support

The overall cost of Life Support is approximately $1,000,000,000. ECLIPSE's life support subsection attempted to incorporate technology with high technology readiness levels in order to reduce the cost of life support. Many of the life support systems will be able to be taken almost directly from the ISS and, after scaling appropriately, applied to the fly-by mission. Certain systems, especially methane pyrolysis and the dry mass processing unit, are currently at a low TRL, but are essential to closing life support loop.

Historically, there are no life support systems on which to base this cost model. That being the case, ECLIPSE per-

formed a first order cost estimation for the life support systems utilizing the Advanced Mission Cost Model developed at NASA's Johnson Space Center. The life support systems were modeled as a 5000-kg (11000-lbs), high difficulty, 1st generation, manned spacecraft. Table X shows the input data utilized and the resultant cost adjusted for inflation.

	Weight (kg)	Block Number	Difficulty	Initial Estimate of Cost ($ billions)
Life Support System	5000	1	High	2.43

TABLE 14: Metabolic requirements and food masses required by crew members on long-duration space flight.

Since the Advanced Mission Cost Model assumes the life support system is an entire manned habitat, the cost of the capsule, $183.5 million (MPLM and Dragon) can be deducted to account for established infrastructure. In an effort to achieve a more reasonable budget for each subsystem, Table X shows the budget allotted to each subsystem according to a representative weighting factor based on the importance, size, and power loading of the system. Furthermore, many of systems are currently above a Block Number of 1; this being the case, Table X shows the itemized reduction representative of the subsystem's overall TRL and is increased for systems whose components are already in development by another company. These subsystems are composed of individual components detailed in Appendix J. The overall segment development factor accounts for the average of various costs incurred by the individual component sources such as private industry or government agency adaptation.

Alternatively to the proposed mechanical life support system, if the Water Walls Architecture is chosen as the advanced life support system cost can be significantly reduced. Water Walls are already under heavy development, have funding, and their level of technological readiness is such that it can be easily adapted to this mission. Nevertheless, the novelty of the ECLIPSE's life support goal will make these systems a significant portion of the total cost of the mission.

TABLE 15: Cost estimation for various life support segments

Subsystem	System Factor	Budget ($Bil)	Segment Development Factor	Development Deduction ($Bil)	Final Cost ($Bil)
Atmospheric Control System	10%	0.24	80%	-0.19	0.05
Atmosphere Revitalization System	28%	0.68	65%	-0.44	0.24
Gas Storage	10%	0.24	75%	-0.18	0.06
Fire Detection and Suppression	2%	0.05	70%	-0.03	0.01
Thermal Subsystem	5%	0.12	85%	-0.10	0.02
Waste Subsystem	12%	0.29	10%	-0.03	0.26
Water Subsystem	17%	0.41	50%	-0.21	0.21
Food Subsystem	9%	0.22	70%	-0.15	0.07
Human Accommodations	4%	0.10	70%	-0.07	0.03
Miscellaneous Items	3%	0.07	30%	-0.02	0.05

Phyical Health

The overall cost of Physical Health is estimated as $987,000.00. This cost consists of equipment for crew health and experimental technology. Overall cost for crew health entails technology to predict any health issues that may arise and mitigate any issues that occur. The experimental aspects consist of diagnostic equipment for the crew to conduct research of human body on deep space and experimental items to conduct a variety of scientific research.

This feature allows for outside entities to invest in getting outside experiments to be conducted during the mission. Furthermore, the equipment required for physical health was extracted from items used in the ISS, which proves readability and cost efficiency.

Mental Health

The total Mental Health total cost is approximately $950,000.00. During the mission the two most important things for mental health are the lighting and noise management. Both of these items are available in the public market, which indicates the items are cost efficient. To maintain the mental health of the crew during the mission, it is necessary to have a psychiatrist accessible for any situation. Due to the particularity of this situation the average salary for a psychiatrist specialized in isolation cases was chosen. After the mission, it is critical to be able to smoothly transition the crew back into society, which requires a public relations specialist. Due to the specialization of both of these personnel, the cost flexibility is minimal.

System/Item	Cost	Total Cost	Comments
Launch Systems			
Falcon 9	$56,500,000		[105]
Falcon Heavy	$154,200,000		$77100000 per launch [105]
RL10B-2	$30,000,000		[106]
LOX	$46,200		[107]
LH2	$23,600		[108]
LOX Tank (Al 2195)	$26,300		[109]
LH2 Tank (Al 2195)	$47,300		[109]
Tank encasing shell (Al 2195)	$62,400		[109]
SpaceX Fairing Lengthening	$21,000,000		[110]
SpaceX Fairing Diameter Expansion	$12,600,000		[110]
ISS Use (Non-crew Time)	$194,300,000		[111] [112]
		$ 275,000,000	
Power System			
Solar Panels	$2,000,000		Purchasing from Spectrolab. Costs approximately $250 per Watt [113] [114]
		$ 2,000,000.00	
Radiation			
Materials			
Aluminum	$5,190		91.2 (cost/unit)* 57 (units) (sheets: 0.32″x4′x10′) [115]
HDPE	$167,000		365.53 (cost/unit)* 457 (units) (1″x4′x8′) [116]
Manufacturing			
Aluminum	$40,000		wage for master welder [117]
HDPE	$234,000		cost of 5 persons working at $150/hour to form 13 layers at 1 inch thick ~ 33 cm [118]
		$ 446,000	
Spacecraft			
MPLM	$100,000,000		
SpaceX Dragon	$83,500,000		Per ISS Flight (not including Falcon 9 Launch). The majority of Dragon craft will maintain reusability
Modifications to Space X Dragon			
Vehicle Customizations	$30,000,000		
Single Use Heat Shield	$20,000,000		
Lengthened Mission Duration	$20,000,000		

TABLE 16: Overall cost break down of the entire mission. The total costs are rounded due to the accuracy of the cost approximation.

		$ 254,000,000	
Communication			
DSN reservations	$7,470,000		Using all stations at various times on an average of 0.5 hours/day
Near Earth Network	$1,310		Using Ka-band
		$ 7,478,000	
Physical Health			
Express Racks	$150,000		Three racks required
Ultrasound Machine	$10,000		Estimation from ground-based equipment
ESWL-capable Ultrasound Machine	$110,000		Developer estimation
SLAMMD	$5,000		Developer estimation
PFS	$4,000		Developer estimation
Percutaneous Electrical Muscle Simulator (PEMS)	$500		Developer estimation
Actiwatch Spectrum	$400		4 required. Manufacture Page [119]
Hand Grip/Pinch Force Dynamometer	$350		Estimation from ground-based equipment
CPBD	$150,000		Developer estimation
Workstation	$5,000		Estimation from ground-based equipment
Refrigerated Centrifuge	$8,000		Developer estimation
GLACIER	$15,000		Two required; developer estimation
Plant Habitat	$75,000		Developer estimation
Radiation Assessment Dector (RAD)	$50,000		Developer estimation
MERLIN Galley	$6,000		Developer estimation
CGBA	$75,000		Developer estimation
ARED	$150,000		Developer estimation
COLBERT	$110,000		Estimation from ground-based equipment
Food Warmers	$3,000		Two required
NONIN 3150	$800		Bluetooth usb wristox wrist pusle oximeter
Galley-Potable Water Dispenser	$3,000		Developer estimation
Food	$50,000		Based on ISS crew member cost per meal [120]
Clothing	$6,000		Calculated from ISS clothing use standards assuming $15/outfit [121]
		$ 987,000	
Mental Health			
Psychiatrist	$432,000		(2x) Based on average salary of practicing psychiatirists in LA [118]
Public Relation Specialist	$101,000		
Lighting System	$350,000		1000 LED panels, theatrical lighting program [115]
Silentium Noise Canceling Device	$67,500		$4500/item x 150 items
		$ 950,000	
Life Support	$56,500,000		
Atmospheric Control System	$154,000,000		Technology Readiness Level (TRL): 70%
Atmosphere Revitilization Systems	$30,000,000		(TRL): 30%
Gas Storage	$46,000		(TRL): 75%
Fire Detection and Suppression	$23,600		(TRL): 70%
Thermal Subsystem	$26,300		(TRL): 60%
Waste Subsystem	$47,400		(TRL): 105
Water Subsystem	$62,300		(TRL): 25%
Food Subsystem	$21,000,000		(TRL): 60%
Human Accommodations	$12,600,000		(TRL): 50%
Miscellaneous Items	$194,000,000		(TRL): 20%
		$ 1,320,000,000.00	
	TOTAL COST	$ 1,886,000,000	

Risk Analysis

Mission

RISK	RESULT	LIKELIHOOD	MITIGATION
Dragon electronics failure	Loss of communication, trajectory control	2	Investigate backup emergency systems, properly upgrade Dragon components
Interior equipment fire	Potentially catastrophic equipment damage, decrease in cabin air quality	2	Fire suppression, ANITA contaminant control, insulate heat-generating components
CBM failure	De-pressurization, catastrophic failure	1	CBM has built in safeguards
Reaction thruster failure	Loss in one thrust vector	2	Can be compensated for by combination of 17 other thrusters
Engine out	Functionality Unhindered	4	SpaceX standard procedure
Launch delay	Launch 1 or 2: Intervals account for minor delay	2	Take advantage of first possible launch 3 window; develop contingency launch plans
Orbit/trajectory insertion failure	Launch 3: Possible missed launch window, mission scrubbed	3	Include excess reaction thrust fix minor errors
TMI booster ignition failure	Mission scrubbed	2	None
Solar panel failure due to debris	Mission scrubbed	1	Rank vital systems to distribute remaining power
Power delivery failure in one solar panel wing	Segment of power loss, potential mission failure	2	Solar generation from one "wing" can be routed through the other, adding redundancy
Emergency medical event	Reduced to 1/2 power generation capability	3	Emergency handbook, tools and surgical enclosure; extensive training
Life Support Mechanical System Failure	Crew death/mission failure	2	More Redundancy in Mechanical Components; Spare Parts; Routine Maintenance and Inspection During Transit
Water Walls Polyethylene Bag Puncture	Equipment Damage/Loss, Personnel Damage/Loss, Total Mission Loss	4	Multiple Bags can easily perform the same function and maintain system performance
	Equipment Damage/Loss, Degradation in System Performance		

Program Delay

RISK	RESULT	LIKELIHOOD	MITIGATION
Capsule Certification Delay	Pivot to another CCDev capsule or Soyuz; possibly miss 2018 window	2	Create plans with alternate capsules, focus on timeline in SpaceX contract
Falcon Heavy certification delay	Missed 2018 launch window	2	Craft alternate
Methane Pyrolysis Unit Not Ready	Loop Not Closed; Methane Must be Vented; Mission Scrubbed	3	Must ensure this unit is developed according to mission launch schedule
Dry Mass Pyrolysis Unit Not Ready	Loop Not Closed; Storage of Dry Mass Waste; Increase in Materials to be Stored; Mission Scrubbed	3	Must ensure this unit is developed according to mission launch schedule
Medical equipment manufacture delay	Reduced medical capability	4	Include flight-ready equipment
Exercise equipment manufacture delay	Increased likelihood of crew injury	3	Include flight-ready equipment
Experimental equipment manufacture delay	Decreased scientific capacity	4	Include flight-ready equipment
Water Walls Polyethylene Bag Puncture	Equipment Damage/Loss, Personnel Damage/Loss, Total Mission Loss	4	Multiple Bags can easily perform the same function and maintain system performance
	Equipment Damage/Loss, Degradation in System Performance		

Conclusion

Sub-Section	Yes	Partially	No
Cheap			
Spacecraft	X		
Launch Systems	X		
Radiation Shielding	X		
Reentry		X	
Communications	X		
Power Systems	X		
Life Support			X
Physical Health	X		
Experimental Equipment	X		
Mental Health	X		
Simple			
Spacecraft		X	
Launch Systems		X	
Radiation Shield-ing	X		
Reentry			X
Communications	X		
Power Systems	X		
Life Support		X	
Physical Health	X		
Experimental Equipment	X		
Mental Health	X		
Safe			
Spacecraft	X		
Launch Systems		X	
Radiation Shielding		X	
Reentry	X		
Communica-tions	X		
Power Systems	X		
Life Support		X	
Physical Health		X	
Experimental Equipment	X		
Mental Health		X	

TABLE 17: Compliance Matrix

ECLIPSE has designed a mission that can be considered safe, simple, affordable, and realistic. With all major design concerns identified and recognized, innovative ideas have been developed to progress the flyby effort led by Inspiration Mars. ECLIPSE hopes that some of the ideas within this report can be put to use in advancing the cause of human spaceflight and is excited for the prospect of working with Inspiration Mars in developing these ideas further.

This mission will deliver a man and a woman within 200 miles of the Martian surface and will return them safely to Earth to live another day. Most importantly, it will prove that the indomitable spirit of exploration that humans possess is NOT dead, that we are not limited by technological challenges, cost limitations and Earth-side barriers. The members of ECLIPSE believe in this vision. We believe that spaceflight requires bold and "out of the box" thinking. We believe that those passionate about space need to be ready to seize opportunities, adapt to the challenges of tomorrow, and never lose focus. As a team, we have united behind our passion for spaceflight, just as the world has in the past and will again in the future.

Is the hostile and costly expanse of space worth all this energy? The tide of human expansion continues its implacable march. Right or wrong, it is central to human nature to develop and achieve. This has allowed us to utilize Earth's natural resources to a great extent and accomplish extraordinary things. Now, however, we have outgrown the proverbial sandbox at the expense of our planet. While the path to interplanetary life is neither easy nor clear, it is a long journey essential to continued human progress. Vehicle flexibility, life support systems, habitation environments and terraforming techniques must advance now for the sake of generations to come. Commercialized spaceflight is the next step in this journey, and, with this mission, Inspiration Mars can be the herald of a new era.

the indomitable spirit of exploration

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Appendices

Appendix A: Trajectory

This report outlines parameters defining the trajectory for a space shuttle on a fly-by mission to Mars as designed by the inspiration Mars Foundation. The Total period of the trajectory is a 1.4 years. The trajectory was analyzed using a patched conic method, which comprise of a hyperbolic orbit with a velocity of 15.34 km/sec at a deflective angle of 70.5 degrees at burnout to escape the earth's sphere of influence onto an elliptic Hohmann transfer orbit with a velocity of 40.65 km/sec to Mars. Another hyperbolic orbit is encountered as the shuttle moves into the sphere of influence or Mars. The gravitational pull of Mars is used to sling the shuttle back onto an elliptical orbit to earth.

In recent years, space travel has become very important as man seeks to explore and understand the universe. Manned travels to the moon and to the International space station (ISS) have aided in better understanding the universe and has also aided in the conduction of various experiment to benefit and advance mankind. Robots and satellites give ample of data pertaining to the solar system however it has always been a dream of mankind to travel to other planet. This has become the challenge of the century because no studies or data on the effects of an environment on humans beyond the moon and the ISS has ever been conducted and hence the dangers of such a travel are unknown. The first step is to accurately determine a viable trajectory for the mission. This paper presents a trajectory design for a mission to Mars.

The free return trajectory for the fly-by mission to Mars was designed using complex numerical integration and high fidelity programs, and well-defined in the IEEE feasibility analysis report published by the Inspiration Mars Foundation. As such, the patched conic method has been used to simply trajectory calculations and to obtain values of parameter that define the trajectory. The trajectory design for the mission has therefore been divided into 4 major sessions [1], which addresses what happens to the space shuttle as it leaves the sphere of influence of the earth, goes through the sphere of the sun, into the sphere of influence of Mars and back to earth.

Phase 2: Elliptical Hohmann Transfer Trajectory to Mars

An elliptical Hohmann Transfer trajectory from the Earth to the Mars orbit is chosen because it requires a lowest energy for the transfer. Knowing the period of the transfer orbit to be 1.4 years [2], Kepler's third law is used to determine the semi-major axis or the elliptical orbit. The equation below is re-arranged and solved for the semi- major axis.

$$P = 2\pi\sqrt{\frac{a^3}{\mu_{sun}}} \quad (1)$$

In the equation above, is the period in seconds, is the semi-major axis and is the gravitational constant of the sun. The velocity at perigee, also the inertial velocity, can then be calculated via the equation below

$$V = \sqrt{\mu_e\left(\frac{2}{R_P} - \frac{1}{a}\right)} \quad (2)$$

The perigee radius in equation 3 above is the altitude of the International Space Station, where assemble of the shuttle as well as launch is will be held. A summary of the result of these calculations is given below.

Parameter	Value	Units
Perigee Radius	377	279
Period (P)	3.00	3.00
Semi-Major Axis Length (a)	1500	1500
Perigee Velocity (V_p)	4.07	2.08

TABLE 1: Overall cost break down of the entire mission. The total costs are rounded due to the accuracy of the cost approximation.

Phase 1: Hyperbolic Escape Trajectory from Earth

This phase focuses on calculating values of the parameters required to escape the sphere of gravity of the Earth. The orbital velocity of the earth is given by

$$V_{earth}=\sqrt{\frac{\mu_{Sun}}{R_{earth}}}(3)$$

In the equation above, u_{sun} is the gravitational constant of the sun and R_{earth} is the radius of the earth. Therefore the inertial velocity of the shuttle is given by

$$V_{inertia}=V_p-V_{earth}(4)$$

Knowing the inertial velocity, the total energy per unit mass can be calculated via the equation below, where R_{SOI} is the radius of the sphere of influence of the earth

$$\varepsilon=\left(\frac{V_{inertia}{}^{2}}{2}-\frac{\mu_{earth}}{R_{SOI}}\right)(5)$$

The hyperbolic velocity (Velocity at burnout) can therefore be obtained from the equation below

$$V_{hyperbolic}=\sqrt{2\left(\varepsilon+\frac{\mu_{earth}}{R_{Perigee}}\right)}(6)$$

The circular velocity in Lower Earth Orbit (LEO) can be obtain by

$$V_{circular}=\sqrt{\frac{\mu_{eaerh}}{R_{perigee}}}(7)$$

Therefore the change in velocity from the circular LEO orbit to the hyperbolic velocity is

$$\Delta V=V_{hyperboic}-V_{circular}(8)$$

This change in velocity must occur at a position that is perpendicular to the direction of motion of the earth. To determine the apt position to apply the burnout velocity, the eccentricity of the hyperbolic orbit must be determined. This is done via the equation below

$$e=\sqrt{\left(1+\frac{V_{inertia}{}^{2}V_{hyperbolic}{}^{2}R_{perigee}{}^{2}}{\mu_{earth}{}^{2}}\right)}(9)$$

The true anomaly of the asymptote of the hyperbolic orbit is

$$\eta=\cos^{-1}\left(\frac{-1}{e}\right)(10)$$

and the orbit will have an asymptote offset of

$$b=\frac{R_{perigee}V_{hyperbolic}}{V_{inertia}}(11)$$

The table below summarizes the results of the calculations.

Parameter	Value	Units
Earth orbital Velocity (V_{earth})	29.78	km/s
Inertial Velocity ($V_{inertia}$)	10.87	km/s
Total energy per unit mass	58.64	km^2/s^2
Hyperbolic (Burnout) Velocity ($V_{hyperbolic}$)	15.34	km/s
Circular Velocity ($V_{circular}$)	7.69	km/s
Eccentricity (e)	2.99	
Velocity deflection (n)	250.5	Degrees (counter-clockwise)
Impact parameter (b)	9.526×10^3	km

TABLE 2: A table of values the define a hyperbolic escape from earth

Appendix B: Spacecraft Design

Development Timeline

SpaceX is developing and testing the Dragon under the NASA CCDev program [2]. The objective of this program is to produce a private vehicle capable of U.S. manned mission to LEO and ISS, operational by 2017 [6]. The SpaceX Dragon is the closest to achieving this goal of all CCDev participants. It has flown two ISS resupply missions along with multiple other successful reentries [2]. These unmanned flights have proven the dragons structural and heat shield integrities. SpaceX plans its first manned Dragon flight in 2015, between two and three years before the chosen Jan. 5th, 2018 launch date of the ECLIPSE mission [8]. This capsule has extensive real world testing with a reasonable path to manned certification. Furthermore, the SpaceX company philosophy and history have demonstrated quick and goal-driven development. This will be beneficial in adapting the capsule to the Inspiration Mars mission design.

Boeing CST-100 is also under the NASA CCDev competition. SpaceX and Boeing are competing for this NASA contract and will be on similar time schedules. The CST-100 is not as developed as the Dragon at this point, but still looks feasible for 2018 usage. Boeing plans the capsules first piloted orbital flight in 2016, with NASA utilization beginning 1 year later, 2017 With Boeing's complete cooperation, it is realistic to have a version of the CST-100 customized and certified for a 2018 Inspiration Mars launch. Boeing has experience developing quality products and sticking to development timelines and would also be a positive partner to this mission.

The SNC Dream Chaser is the third vehicle under CCDev. This vehicle has undergone atmospheric tests of its landing gear, lifting body and other various equipment, but like the CST-100 has yet to make an orbital reentry. The first orbital flight is scheduled for 2016, although this is unmanned and automated. SNC hopes to fly the first piloted version in 2017[9]. This will likely be too late for utilization in the Inspiration Mars mission. Furthermore, any number of delays could crop up in final development and testing, which would certainly move this vehicle out of reach for an early 2018 launch.

The NASA Orion will not be certified for manned flight in time for the 2018 launch windows. NASA has scheduled the first unmanned, suborbital reentry test for late 2014. A second test, also unmanned, is scheduled for 2017. The maiden manned voyage will happen no sooner than 2021 [10]. The capsule is being constructed by the ESA, who have already pushed back the Preliminary Design Review. It is possible that further delays will occur, making the Orion an unrealistic option for any serious short-term deep space plans [10].

The Dragon has the distinct advantage in development timeline. While all capsules must pass certifications and critical milestones before they will be ready, the Dragon has the shortest path to manned flight and can be reasonably expected to be available in 2018. The CST-100 is also a realistic option, although there will be less room for development error. The Dream Chaser poses a large risk of delay and would only be acceptable if it were distinctly superior to the above two vehicles. The Orion will simply not be available for a manned 2018 launch and is therefore out of consideration.

Launch

The vehicle must carry the astronauts to the ISS, where they will stay while the final craft is assembled and finally enter and embark on the Mars FRT. The CST-100 is being designed for usage with multiple launch vehicles (U.L.A. Atlas V, Delta IV and SpaceX Falcon 9), adding launch vehicle flexibility[3]. Dream Chaser is currently being designed for the Atlas V [11]; Dragon is exclusively for SpaceX Falcon series launch vehicles [1]. The CST-100 gives ECLIPSE the opportunity to pivot on Launch vehicle selection if the need arises. This is the only major factor that differentiates the three in their basic role of ISS transport.

Reentry

The vehicle reentry will be one of the most dangerous mission segments due to the high return speed of approximately 14km/s. This will generate intense heat and drag forces that can quickly destroy a craft.

The SpaceX Dragon has a big advantage, simply because the craft has successfully reentered on multiple occasions [2]. The PICA-X dragon heat shield is highly capable, being designed to withstand temperatures experienced during lunar or Martian missions[12]. It is based off of NASA's phenolic impregnated carbon ablator shield (PICA), which has already endured 2500C reentry temperature at a speed of 12.51km/s [13]. It has proven to be reliable and high-performing.

Boeing CST-100 uses the Boeing Lightweight Ablator. The Dream Chaser utilizes a unique blended wing craft shape with its own thermal protection system. These have never seen real world reentry. Furthermore, both vehicles are designed exclusively for LEO reentry of <10km/s. Their shields are likely underdesigned for the exponentially higher return forces of a deep space reentry, although not enough testing information is public to be sure.

The Dragon has a large lead in this critical mission component. Both CST-100 and Dream Chaser would require rigorous verification and testing before ECLIPSE is comfortable utilizing these launch vehicles for reentry.

Cost

All vehicles will require customization to fit the Inspiration Mars mission on top of their base cost. There are no publicly known hard cost numbers for the each vehicle. With Orion out of the running, the three remaining vehicles must be compared to determine the most affordable projected option.

There are many pieces of evidence saying that SpaceX development philosophy is efficient and cost-effective. The company leadership benefits from Silicon Valley ideals – "lean manufacturing, vertical integration, flat management"- all designed for cost-efficient operation. Reducing the cost of spaceflight, manned and unmanned, is central to the SpaceX company mission. Development of the Dragon naturally reflects that. For example, their heat shield material PICA-X is approximately ten times cheaper to manufacture than the highly successful NASA material NASA PICA, while maintaining performance [7]. This cost-effective mentality will be an ideal partnership for the ECLIPSE mission.

The Dragon is the smallest and lightest of the capsules. It is designed for simple functionality. Boeing has devoted resources to interior design and user interface; SNC has devoted resources to their blended wing design to create easy reusability. While exciting, both of these features do not contribute to this particular mission and will only increase vehicle cost. The base purchase cost of the Dragon will likely be less than CST-100 or Dream chaser, while inevitable customization will be streamlined and efficient.

Command Module Conclusion

The SpaceX Dragon is the most feasible option available to ECLIPSE. Its positive track record, impending manned certification and cost-competitive design will give the greatest chance of success.

As stated above, the living space of even the largest capsule is insufficient for the 501 day mission duration. This must be expanded to 66.5 m3. This will be achieved by the addition of a habitation module. ECLIPSE considered Bigelow inflatable modules, but determined that these were not feasible due to development uncertainty and internal geometry of their modules, detailed in appendix ___.

Bigelow Aerospace is developing innovative inflatable module technologies which provided an alternative to the industry standard alloy shelled spacecraft. This innovative concept utilizes a myriad of semiflexible fabrics compressed or "folded" around a rigid central column at launch, which is then inflated to size. Due to the low mass and small diameter upon launch, this technology has the potential to deliver large habitats on relatively small rockets [122].

The BEAM can be considered Bigelow's pilot module. It is scheduled for installation on the ISS in 2015 for testing and technology demonstration. This module possesses 18 m3 of livable volume around its central pillar. While a number of these modules end to end would provide the necessary habitable volume there would be less than a meter of floor space between pillar and wall. Larger pieces of equipment such as the Advanced Resistive Exercise Device (ARED) and life support systems will not fit anywhere in the module assembly. Bigelow is also developing a scaled up model, termed the BA330. This has an internal volume of 330m3 and will easily fit all necessary equipment and supplies. However, its outside diameter of 6.7m would require an expensive and heavy shield to provide the necessary radiation shielding.

NASA Multi-Purpose Logistics Module

The NASA MPLM is a module developed in the late 1990s, initially used as a cargo transportation module in the space shuttle missions. The module should be configured with a CBM on one end for berthing with the Dragon and a CBM compatible automated mechanism for mechanical assembly with a motor (detailed in section 2.3.2) This module's 4.56m diameter and 6.40m overall length provide an ideal volume for the mission. The total internal volume is approximated in Appendix A as 92.6m3.

Living Module Conclusion

The Bigelow expandable modules are not feasible for this mission due to their dimensional configurations. Alternatively, the MPLM provides a comfortable amount of space for astronaut mobility and all equipment while keeping the assembly's size small enough to be effectively shielded. The MPLM is a proven module with a long usage history, and as such does not have required any development and provides a spacious environment. ECLIPSE's mission objectives can be achieved with the MPLM and it is the final selection for this mission.

Appendix C: Launch Systems

	Mass (kg)
MPLM	4082
Radiation Shield	19,000
Life Support	6,713
Physical Health	1960.52
Electrical	1740.77
RL10B-2 Booster	301
LOX	42,972
LH_2	7,308

	Mass (kg)
Booster Propellant Tanks	3,309
Capsule + Trunk	4617.6045
RS-72 Engine (Reentry)	138
N2O4	1757
MMH	3513
Reentry Propellant Tanks	23.1655
Crew	163.015

Appendix D: Radiation Shielding

GCRs are the most dangerous type of radiation in deep space. These particles originate from supernova remnants in interstellar space, and are composed of nuclei of atoms that have had their surrounding electrons stripped away and travel at nearly the speed of light. Their intense speed and composition are due to exposure to magnetic fields of supernova remnants for several million years. They are randomly accelerated and eventually gain enough speed and energy to escape into the galaxy and become cosmic rays. In interstellar space, cosmic rays may collide with interstellar gas and produce gamma rays, which is currently the only method to detect GCRs[1] [2] . GRCs generally have energies ranging from 100 MeV to 10 GeV, and the highest ever measured was 1020eV (Mewaldt). GRCs consist mainly of 85-89% hydrogen (protons), 10-15% helium (alpha particles), and 1% high-energy and highly charged particles (HZE, heavy ions with Z>2 and high E) (Mewaldt) (Zeitlin and al.). Though HZE particles are less abundant, they possess significantly higher ionizing and penetration power, and greater potential for radiation-induced damage. Very high energy cosmic rays also have the potential to produce "secondary" particle showers consisting of gamma rays, electrons, and positrons when colliding with other particles. The Sun's magnetic field can affect the travel of cosmic rays and deflect them because moving charged particles electromagnetic effect. However, the average intensity of GCRs is highest when there are fewer sunspots, and when the Sun's magnetic field is weakest and less able to deflect them. Intensity also increases with distance from the Sun (Mewaldt[3] [4]). HZEs from GCRs are particularly damaging to the human body as they destroy cells and cause single and double-strand breaks in DNA, as well as associated base damage (NASA). This NASA image provides an excellent representation of HZE damage.

SPEs are caused by solar flares and/or coronal mass ejections (CMEs). During a solar flare or CME, large amounts of protons, and occasionally helium and HZE ions, are released. These particles may reach the Earth in two hours to less than 30 minutes, and tend to be difficult to predict when they occur (Understanding Space Radiation)—[5]. Only increases and decreases in solar flares and CMEs can be predicted. Sunspots increase and decrease over an 11-year cycle. [6] When the Sun increases in sunspots, it becomes brighter and produces more SPE and CME, increasing the amount of radiation in the solar system. Because of this, only frequencies of SPE's and CME's can be predicted (Rask, Vercoutere and Navarro). SPEs generally have energies around 10-500 MeV (Mewaldt). Like GCRs, SPEs can also produce "secondary" particle showers when colliding with other particles, which also pose another great health risk for astronauts.

The Van Allen belts are a layer of high energetic particles trapped by the Earth's magnetic field at an altitude of 1,000 to 60,000km from the Earth's surface. The particles that make up the belts come from particles from the above two forms of radiation that happen to collide with the Earth's atmosphere and become deflected by the Earth's magnetic field (Rask, Vercoutere and Navarro). Since only minimal time is spent in the Van Allen belts and the survivability of this environment is well known, it does not have as significant of an impact on the mission as GCRs and SPEs and, therefore, does not need to be as heavily considered.

Appendix E: Reentry

Ballistic model

The equation used to calculate the maximum acceleration is

$$a=(V^2 * b * \sin(\gamma))/2e$$

where

V= reentry velocity in reference to the earth

b = atmospheric scale height, a parameter that describes the density profile of the earth = 0.000139m^-1.

e = 2.718

γ= entry angle

Using 14 km/s as the reentry velocity and 6.5 degrees as the entry angle the maximum deceleration felt by the capsule would 57.8 g's.[176]

Skip reentry equations

In order to calculate the skip reentry process the equations of motion where derived. For a capsule using a skip reentry method [38]

$$r = Rv * \sin(\gamma)$$

$$Rv = - D/m - g * \sin(\gamma)$$

$$Rv\gamma = - L/m - g * \cos(\gamma) + Rv\,\hat{}2/r \cos(\gamma)$$

equations that describe the forces acting on the spacecraft

$$D = 1/2 * \rho * CD * Rv2 * S = \text{drag force}$$

$$L = 1/2 * \rho * CL * Rv\ 2 * S = \text{lift force}$$

CD and CL define the drag and lift coefficients of the capsule were not listed by the Space website the following

Appendix F: Communication

Parameter	
Maximum S/C Distance	3.7425E8 km
Uplink Transmitter Power [123]	200W - 400 KW
Uplink Frequency Band	X Band, X to Ka band*
Uplink Command Mod. Index [42]	1.2 radians
Uplink Ranging Mod Index [124]	0.22 to 0.5 radians
Uplink Transmit Antenna Gain	85.87dB?
S/C HGA Receive Gain/Loss	45.2dBi
S/C MGA Receive Gain/Loss [125]	15 dBic
S/C LGA Receive Gain/Loss	8.4dBi
Telecommand Data Rates [126]	X band 35m - 182.6 Mbytes, 75m - 727.5, Ka band 35 m - 659.6, 70 m - 1772.1
Telecommand Bit-Error-Rate [127]	ranges from 10e-2 @ 2 SNR and 10e-4 @ 2.4 SNR
S/C Receiver Noise Temperature [128]	lowest 100 K

S/C Receiver Bandwidth [124]	ranging channel bandwidth - 1.5 kHz to 819 kHz
Turnaround Ranging [129]	3360/3599
Required Ranging Accuracy [130]	2 m
SC Transmitting Power	35W
Downlink Modulation Format	16 -M-ary quadrature amplitude modulation (QAM) [131]
Downlink Frequency Band	Ka/X band
S/C HGA Transmit Gain/Loss	56.4dBi
S/C MGA Transmit Gain/Loss [132]	12 dBi
S/C LGA Transmit Gain/Loss	8.8dBi
Downlink Receive Antenna Gain	85.87dB
Telemetry Data Rates [133]	115.2 kilobits per second
Downlink Telemetry Mod Index [134]	4.167
Telemetry Coding & Code Rate [135]	13.8Mbit/s

Telemetry Frame Length [136]	Minor frame length - 64 words of 8 bits per word, Major Frame- 64 Minor frames
Frame Deletion Rate [137]	10e-4 with a frame length of 1152 bits
Telemetry Bit-Error-Rate [138]	6.2 e−2
Subcarrier frequency and format [139]	16 kHz
Ground Station Implementation Losses [140]	- 2dB
Downlink Ranging Mod Index [141]	0.1rad →5rad
Hot Body Noise [142]	29.8 dB below the noise power of the onboard reciever
Ground station 70m antenna gain	-210dBm
Ground station 34m antenna gain BWG	66.8 dBi
Ground station 34m antenna gain HEF	40 dBi

Appendix G: Power Generation

The communication system requires 350-W, living configuration needs two kilowatts, physical health necessitates 496.2-W and life support must have 4-kW. This means that the space craft must be able to draw up to seven kilowatts of power at any given moment.

Solar System Fundamentals

As seen in the figure below, photovoltaic panels are connected to a network of components that make up the primary power system. The primary power system is the system used to charge and discharge the batteries, as well as to direct to proper amount of power to the secondary system. The secondary system is the system where the electricity is divided and sent to its various loads. In between these two systems is a Direct Current to Direct Current Converter (DDCU). The DDCU steps down the DC voltage from 133-177 Volts to 120 Volts.

The first thing that happens in the primary power system after the solar panel creates a current is it passes through the Sequential Shunt Unit (SSU). This is the primary power regulation device, and it provides a constant 160 Volts. The SSU works by continually changing various connections between shunt and cascade in order to keep the output voltage steady. Therefore if the output of the solar panels suddenly spikes, the entire power system will not be fried because the SSU changed its configuration to keep a constant 160 Volts. There will be two SSUs aboard the space craft, one for each wing.

After the SSU, the DC Switching Unit (DCSU) distributes power between the batteries and the secondary power system. Remote Bus Isolators are used to direct the power flow either from the solar cells to the secondary system or the batteries, or to direct from the batteries to the secondary system when the solar cells are blocked from the sunlight. Two DC Switching Units are necessary to support the power system for this mission.

Battery Charge/Discharge Units (BCDUs) come after the DCSU and charge the batteries when there is excess power coming from the solar panels, or discharge them when more power is required. The BCDU consist of Control Power Remote Bus Isolators (CPRBI) and Fault Isolators (FI) which act as circuit breakers and battery discharge current limiters respectively. One BCDU is required for every two batteries. The batteries to be used on this expedition are light weight nickel-hydrogen cells.

In addition to the BCDUs coming off of the DCSU, the BCDU is also hooked up to the Main Bus Switching Unit (MBSU). This serves as the connection between the primary and the secondary power system; It has an output of 133 to 177 Volts. The mission will require two MBSUs.

The final stage before the secondary power system is the DDCU. This stage uses a transformer to down convert the 133-177 Volts to about 120 Volts. All of the equipment aboard the Dragon requires either 120 Volts or 28 Volts of DC current. If 28 Volts is required then another down converter will be necessary. After the DDCU comes the secondary power system. On space craft, different equipment will often have different loads, power, and current requirements. Therefore in order to ensure safe and reliable operation, a secondary power system is employed which prepares the power for the desired equipment. Two versions of the DDCU exist for this mission's purpose, the DDCU-I (Internal) and the DDCU-E (External).

An important design note is the available interaction between the power channels from each wing. For the sake of safety, the solar panel system will be designed to allow for one power channel to use equipment from the other channel. In the case of a malfunctioning piece of equipment in one channel, the crew will still be able to survive by sharing the other power channel.

Appendix H: Nutritional Breakdown

In order to calculate the food required for a man and woman during a 501 day mission, a crew age of 30-60 was assumed with a weight W. The content of the daily caloric intake (DCI) was assumed to be 12-15% protein (4kcal/g), 50-55% carbs (4kcal/g), 30-35% fat (9kcal/g), and 10-25-g of fiber.

Calculations for the male crew member weighing 68 kg:

$$DCI_m = 1.7 * (11.6\,W + 879)$$

$$DCI_w = 1.6 * (8.7\,W + 829)$$

	Energy (kcal/day)	Mass (g/day)
Select whole table	2835	754
Protein (12-15%)	528.15	133
Carbs (50-55%)	1936	484
Fat (30-35%)	1232	137
Fiber (10-25-g)		10
	Total	754 g
	Water	2.2 kg

	Energy (kcal/day)	Mass (g/day)
DCI	2604	556.5
Pr Adjust table row	359.7	97.5
Carbs (50-55%)	1318	358
Fat (30-35%)	839	101
Fiber (10-25-g)		10
	Total	556.6
	Water	2.2 kg

Assuming the volume of ready-to-eat meals (MRE's), the mass and volume of the nutritional requirements required for 500 days are:

Total food for 1 man and 1 woman for 501 days: 656 kg

Total volume of food: 2.4 m^3

Appendix I: Experimental Equipment Justification

Health Monitoring

Ultrasound Machine

Currently, the main diagnostic tool included on ISS is a portable ultrasound machine. Ultrasounds are cheap, versatile, easy to use, and non-invasive. In addition, most ultrasounds can be self-administered provided adequate training [143]. For these reasons it is recommended that the crew be trained on the included medical diagnostic portable ultrasound for diagnostic purposes. The addition of a medical ultrasound will also increase the experimental breadth of the mission.

ESWL-Capable Ultrasound Machine

A second ultrasound, capable of Extracorporeal Shockwave Lithotripsy (ESWL), would be ideal. One mission-critical side effect of the altered cardiovascular system includes, due to the hyper-activity of the kidneys and dehydration, kidney stones. To mitigate this, several research groups are designing microgravity-favorable methods of dislodging kidney stones using ultrasound probes through ESWL. ESWL was developed in 1980 for the as application of degrading kidney stones using focused ultrasound waves. An ESWL-capable ultrasound is much higher powered than a conventional ultrasound machine, implying the necessity of a second machine. However, current ESWL

procedures do not translate well to space travel. The high powered waves create a risk of renal damage from the ultrasound vibrations, which could be damaging if the kidneys of the subject are in poor shape. In addition, the procedure is usually conducted under anesthesia. The use of anesthesia in microgravity has, to date, not been tested and is elaborated upon below. Due to the high level of accuracy necessary for this procedure, patient stabilization will be necessary to minimize organ damage [84]. However, a microgravity-capable system under development by Simon et al. at the University of Washington shows promise by greatly reducing the risk of renal damage through a user-friendly interface that requires little training [143]. The rapid product development and robust testing schedule demonstrated by Smith et al. encourages the inclusion of this device.

7.8.1.3 SLAMMD

Further monitoring of crew health is done by the other contents of the HRF racks. The Space Linear Acceleration Mass Measurement Device (SLAMMD) is the only microgravity-capable mass measurement system, using Newton's Second Law to calculate mass [90].

7.8.1.4 Pulmonary Function System

Lung health is suggested to be monitored through the use of the Pulmonary Function System, a set of three modules capable of recording a variety of respiratory and cardiovascular measurements [144]. The medical workstation computer is suggested to be a portable computer capable of running the multitude of software necessary to support the medical studies. The refrigerated centrifuge increases the scientific versatility of the mission, enabling the centrifugation of biological samples while maintaining the integrity of the sample [85]. In conjunction with the later described GLACIER cold stowage units, quality biological samples can be perfectly preserved for analysis on Earth [85].

7.8.1.5 Actiwatch Spectrum

The Actiwatch, developed by Philips Healthcare, is an actigraphy-logger robust enough for monitoring the gross motor activity of astronauts. The Spectrum model was selected due to its high level of comfort, robustness, and the extended battery-life. The one-year battery life makes it ideal for this application. Actiwatches have been used on the International Space Station for research purposes in the past and data collected can be stored on the watch indefinitely until downloaded. [86] [87]

7.8.1.6 Hand Grip/Pinch Force Dynamometer

Isometric contraction of the hand and adequate pinch strength are necessary for dexterous tasks during this mission and other long duration missions. The hand grip and pinch force dynamometers are capable of measuring an isometric contraction within the physiological range of forces [145].

7.8.1.7 Blood Pressure/Electrocardiograph

As previously mentioned, a cardiovascular fluid shift occurs in microgravity that redistributes the blood volume in the body. The fluid shifts out of the legs and pools near the heart, increasing the blood flow to the trunk and the brain. This shift increases the pressure on the vessel walls and long term exposure may hurt cardiovascular health. A blood pressure device is necessary to monitor the fluid shift and overall health of the astronaut. Likewise, an electrocardiograph is imperative to monitor heart health with decreased overall blood volume. ISS currently uses a compact blood pressure device with a electrocardiograph manufactured by SunTech Medical Instruments that is compatible with the EXPRESS rack. [89]

7.8.1.8 Heart Rate Monitor

For effective aerobic exercise, it is important to monitor the heart rate to ensure that the heart rate is in the proper zone for cardiovascular health and strengthening. A low-profile watch and chest strap are used on ISS, enabling astronauts to exercise unencumbered while staying healthy. Although the currently used Heart Rate Monitor (HRM) requires the crew to change the battery on orbit, the crew would be able to reliably and cheaply record heart rates

during aerobic exercise. It is suggested that the crew be given the knowledge to change the battery of the HRM watch to extend the lifetime of the apparatus. [89]

7.8.2 Biomedical Research

7.8.2.1 Refrigerated Centrifuge

An experimental capability of refrigerated centrifugation of biological samples increases the scientific diversity of the mission experimental platform. The Refrigerated Centrifuge (RC) in use on ISS is used to separate liquid biological samples into areas of varying densities for further processing or storage. A wide range of sample sizes, centrifugation speeds, and functional refrigeration range makes the RC the most capable centrifuge for the purposes of the mission [146].

7.8.2.2 PEMS

In support of musculoskeletal health and, in particular, the neurological control of muscles in microgravity, the Percutaneous Electrical Muscle Simulator (PEMS) is suggested to be flown. Light-weight, low-cost, and proven to work well in microgravity, this system is capable of initiating a contractile response of the non-thoracic muscles, activating them with an electrical pulse.

7.8.2.3 GLACIER

There are various cold stowage systems available. The most capable of which is the General Laboratory Active Cryogenic International Space Station (ISS) Experiment Refrigerator (GLACIER). The GLACIER stands out amongst the other options because it is compatible with a variety of currently used space vehicles such as Shuttle Middeck, MPLM, and ISS, as well as future vehicles such as SpaceX Dragon, and Orbital's Cygnus Vehicles. It also has the largest carrying capacity of 11.35 liters. The drawback to this device is that it must be powered. It is not passive, therefore more information about the capsule's power capabilities should be understood before this device is settled upon. With large storage capabilities, it is not only possible to bring tissue samples back to Earth, but also to bring samples into space for testing. The large amount of space provided by the GLACIER Cold Stowage system can be utilized by various companies who wish to perform tests in low gravity for long periods of time. This capability will allow Eclipse to lease storage space for temperature sensitive material and ultimately increase funding for the mission. This may be one of the most profitable experimental capabilities for the mission.

7.8.3 Biological Research

Similar to the use of the HRF racks, experimental versatility will be enabled through the use of an Expedite the Processing of Experiments for Space Station (EXPRESS) Rack. The EXPRESS rack consists of 8 Middeck Lockers and 2 Powered ISIS (International Subrack Interface Standard) Drawers. [147]

7.8.3.1 Plant Habitat

Growing plants during a long-duration manned space flight mission provides many added health benefits. Conversion of ambient carbon dioxide to oxygen using photosynthesis reduces the workload on the life support system. In addition, the ability to grow food in space may be an adequate way to maintain diversity and interest in food, introducing fresh foods into the diet. Growing plants in the space environment will further understanding of processes that are necessary for plant life on earth. By comparison to plants grown on earth, it will be seen if/how various chemical processes are governed by gravity and other earthly effects and which processes are still reliable in space. It is this aspect that will attract investors and companies to fund the mission because it may provide solutions to food production issues on Earth as well as in space. NASA Kennedy engineers are in the process of developing a compact plant research habitat, completely supported and compatible with EXPRESS racks. The plant habitat is being designed to attract principal investigators and researchers interested in large growing areas for long-duration plant cultivation. A removable science carrier enables easy and fast turnover of plant experiments lasting one

to three months, enabling up to 17 experiments over the course of the mission. A launch date in December 2015 puts the development timeline for the plant habitat well within the timeline of the Inspiration Mars mission. [90]

7.8.3.2 Commercial Generic Bioprocessing Apparatus

Not all researchers will have the funding to have a space on the HRF or EXPRESS racks primarily for their experiment. Therefore, the Commercial Generic Bioprocessing Apparatus (GBA) is recommended as an experimental platform to increase the breadth of possible experiments supported on the Inspiration Mars mission. The compact device has, in its lifetime of use on ISS, supported protein crystal growth, insect habitats, plant development, and cell-culture studies. Customizable inserts allow for versatility, enabling multiple regions of independent, highly accurate thermal control as well as data and video observation. The Multiple Orbital Bioreactor with Instrumentation and Automated Sampling (MOBIAS) acts as a multi-purpose bioreactor complete with culture media and waste bags. Passive gas exchange can be achieved by the Gas-Exchange-Group Activation Packs (GE-GAPs) which also can initiate, mix, grow, and terminate biological experiments. Increased versatility is achieved by the CGBA Science Inserts (CSIs), smaller platforms able to be personalized for researcher-supported projects, complete with video and still-imaging capabilities. The wide array of projects able to be conducted by this piece of equipment makes it necessary for inclusion on this mission. [148]

7.8.4 Physical Sciences Research:

7.8.4.1 RAD

The Inspiration Mars mission proposed is the first case that radiation shielding is utilized as a crucial mission component. As alluded to in the description of the radiation shielding, long-duration manned missions is highly limited by radiation exposure. The success of the Inspiration Mars radiation shielding will be crucial for future missions. Therefore, the Radiation Assessment Detector (RAD), developed for applications on the Mars Science Laboratory, is suggested to measure the amount of radiation exposure that the crew is exposed to over the course of the mission. RAD is a solid state radiation detector telescope and cesium-iodide calorimeter with active coincidence logic used to identify charged particles and scintillators with anti-coincidence logic to identify neutrons and →rays. [91]The conte

Appendix J: Life Support

Subsystem/Component	Technology	Mass (kg)	Volume (m^3)	Power (W)
Atmospheric Control System				
Atmospheric Pressure Control	ISS	83.58	0.18	49.35
Atmosphere Revitilization System				
Carbon Dioxide Removal	Amine Swing Bed	120.00	0.10	
Carbon Dioxide Reduction	Ultra Sabatier	TBD		
Oxygen Generation	Electrolysis	100.00		
Gaseous Trace Contaminant Control	ANITA	60.07	0.28	136.05
Atmosphere Composition Monitoring Assembly	ISS	38.01	0.06	72.45

Sample Delivery System	ISS	24.58	0.03	
Gas Storage				
Nitrogen Storage	Cryogenic	193.07	0.22	2.86
Oxygen Storage	Cryogenic	60.74	0.13	2.02
Fire Detection and Suppression				
Fire Detection System	ISS	3.00	0.00	1.04
Fire Suppression system	ISS	48.00	0.03	0.00
Thermal Subsystem				
Avionics Cooling	Preinstalled on Dragon	N/A	N/A	N/A
Common Cabin Air Assembly	ISS	70.85	0.30	318.31
Avionics Air Assembly	ISS	6.00	0.01	122.50
Atmosphere Circulation	ISS	6.86	0.01	42.70
Atmospheric Microbial Control	ISS	70.00	0.19	0.00
Waste Subsystem				
Solid Waste Collection	ESDM	25.45	0.09	9.80
Solid Waste Treatment	Pyrolisis Tech.	60.00	TBD	TBD
Water Subsystem				
Urine/Grey Water Collection	ISS	3.19	0.01	2.80
Water Treatment	VPCAR + Lypholyzation	407.69	1.41	1982.02
Grey Water Storage Tankage	ISS	186.75	0.46	16.57
Microbial Check valve	ISS	6.07	0.01	0.00
Process Controller	ISS	44.10	0.00	126.00
Water Quality Monitoring	ISS	9.85	0.03	3.30
Product Water Delivery System	ISS	49.90	0.12	3.21
Water Storage		100.00	0.00	0.00
Food Subsystem				
Food Storage		112.50	7.32	672.00
Dry Food Mass		750.00	0.00	0.00

Human Accomodations				
Clothing		443.00	0.27	0.00
Washer/Dryer		56.00	0.18	443.33
Detergent		4.00	0.00	0.00
Miscellaneous Items		498.96	0.50	0.00
Totals		3642.20	11.94	4006.30
	Mass (kg)	Volume (m^3)	Power (W)	
Totals	3642.20	11.94	4006.30	

Two People:

IN		OUT	
Breathe	51.88 mol O2	Breathe Out	45.45 mol CO2
	33.33 mol H2O	Urine	158.31 mol H2O
Drinking	180.00 mol H2O	Flushing	73.67 mol H2O
Food	212.22 mol H2O	Condensate	252.22 mol H2O
Hygiene	40.33 mol H2O	Feces	0.22 kg Feces
Flush	33.33 mol H2O		10.11 mol H2O
	465.89		494.31

Daily Air Changes:

-	51.88 mol O2
+	45.45 mol CO2

Daily Water Changes

-	499.22 mol H2O
+	585.22 mol H2O

Efficiencies

1.00	Urine Processing

	Daily Changes:		Total:	
-	0.27	L H20	136.69	L H20
-	0.21	kg O2	102.93	kg O2
+	0.55	kg C(s)	273.27	kg C(s)
+	0.22	kg Feces	110.22	kg Feces
+	0.00	L Brine	0.00	L Brine

CO2 PROCESSING:

Sabotier:

IN	OUT
45.45 mol CO2	45.45 mol CH4
181.82 mol H2	90.91 mol H2O

WATER STORAGE:

IN	OUT	
494.31 mol H2O	499.22 mol	4.91 mol
27.46 L H2O	27.73 L H2O	0.27 L

Methane Pyrolysis:

IN	OUT
45.45 mol CH4	45.45 mol C(s)
0.73 kg CH4	90.91 mol H2

H2 Separator:

IN	OUT
45.45 mol CH4	45.45 mol C(s)
	90.91 mol H2

H2 STORAGE	O2 RESERVE
IN	OUT
0.00 mol H2	6.42 mol O2
0.00 g H2	0.21 kg O2

GRAY WATER PROCESSING:

IN	OUT
585.22 mol H2O	585.22 mol H2O
	0.00 L Brine

MOLAR MASSES:

Hydrogen	0.00	kg/mol
Carbon	0.01	kg/mol
Nitrogen	0.01	kg/mol
Oxygen	0.02	kg/mol

ELECTROLYSIS:	LR:	1.00	1=H2	2=O2
IN	OUT			
90.91 mol H2O	45.45 mol O2			
	90.91 mol H2			

TEMP:		HUMIDITY:	
18-27	deg C	25-75%	H2O

ATMOSPHERIC COMP:

Min Pressure:	51711.00	Pa
Max Pressure:	103421.00	Pa
Min ppO2:	128.00	mmHg
Max ppO2:	178.00	mmHg
Max CO2:	5.00	mmHg

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